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A SIMULATION MODEL FOR ANALYZING ELECTRICAL NETWORKS IN BUILDINGS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled

"A SIMULATION MODEL FOR ANALYZING ELECTRICAL NETWORKS IN BUILDINGS"

submitted by LARRY WILBUR MILLS in partial fulfillment of the requirements for the degree of Master of Business Administration.

ABSTRACT

This thesis presents a model for generating estimated costs of construction for numerous different electrical distribution networks in a building. The model was developed to aid planning of a building and the design of the electrical system. Attention is directed to describing the relationships used in the model so that an appraisal of the model can be made. The results of a test of the model are presented as an example of some of the benefits afforded by use of the model. Hopefully the model will assist designers and planners and aid the development of other models for related applications.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dr. Boyd M. Harnden for his guidance and valued critiques at each stage of the development of this thesis.

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CHAPTER I

INTRODUCTION

General

Design of an electrical network for a building consists of deciding how to provide power to every electrical device in the building. Because of the large number of electrical devices, the variations in power requirements, and the large number of possible distribution networks to convey the power the analysis and design of the electrical network is complex.

Simulation has proven useful in many fields as an analysis aid for complex problems. With the introduction of the high speed digital computer simulation became a method not only of analyzing analytically insolvable problems but also a device for handling a large number of interrelated variables. Simulation thus lends itself well to the problem of electrical design. However to date no application of simulation to the design of electrical networks for buildings is known to the writer.

Organization of the Thesis

The remainder of this Chapter will be devoted to describing the problem to be solved, the limitations of the study carried out and the objectives which guided the formulation of the model. Chapter II is a literature summary of "Simulation" and provides the reasons for selection of simulation and the program-

ming language "FORTRAN IV", for this study. The design and operation of the model developed in this study is described in Chapter III. Chapter IV outlines a test performed on the model using a hypothetical building. The final chapter summarizes the results of the investigations carried out and lists the conclusions of this study.

Problem Description

Construction cost is a prime consideration in the choice of an electrical distribution system for a building. The cost involved in estimating the construction cost precludes a quantitative analysis of even a few of the many possible designs. Thus normally the selection of a design is made on the basis of intuition and "rules of the thumb".[1]

Purpose of the Study

This study was carried out to develop a practical method to determine the constructions costs for various possible electrical distribution networks in a building. Such a measure of design efficiency can aid early planning of a building layout as well as design of the electrical distribution system for a given building. As a planning tool such a model can be used to estimate electrical distribution costs for various building designs being considered. As a design tool the cost measures can aid selection of an electrical

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[1] One such rule of thumb is: "locate the panels at the center of the area containing the loads the panel is to serve".

distribution system given the layout of the building and electrical requirements.

Four objectives were central in the design of the model presented in this study. The guiding objectives were:

(1) To provide an estimate of the total construction costs dependent upon the electrical distribution design.

(2) To provide sufficient information about each trial design that an analysis of the design and the component costs can be carried out.

(3) Wherever possible provide information about each design which will be required in developing plans and specifications for a design.

(4) To develop a model which is flexible enough to allow analysis of a broad range of electrical systems with only minor changes required in the basic model.

Simulation, particularly when combined with a flexible programming language such as "FORTRAN IV" is best equipped to attain the above objectives.[2]

Limitations of the Study

This study is limited to the analysis of one part of the total problem of electrical design in buildings. The model derived in this study estimates construction costs for the power distribu-

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[2]The attributes of these items are described in Chapter II.

tion network. Illustration "A", on the following page, shows a simplified typical power distribution network. The costs which are dependent on the design of such a network are the costs of: (1) the main panel, (2) panel feeders, (3) panels, and components and; (4) wire and conduit required to carry the power from the panel to each group of electrical devices (loads).

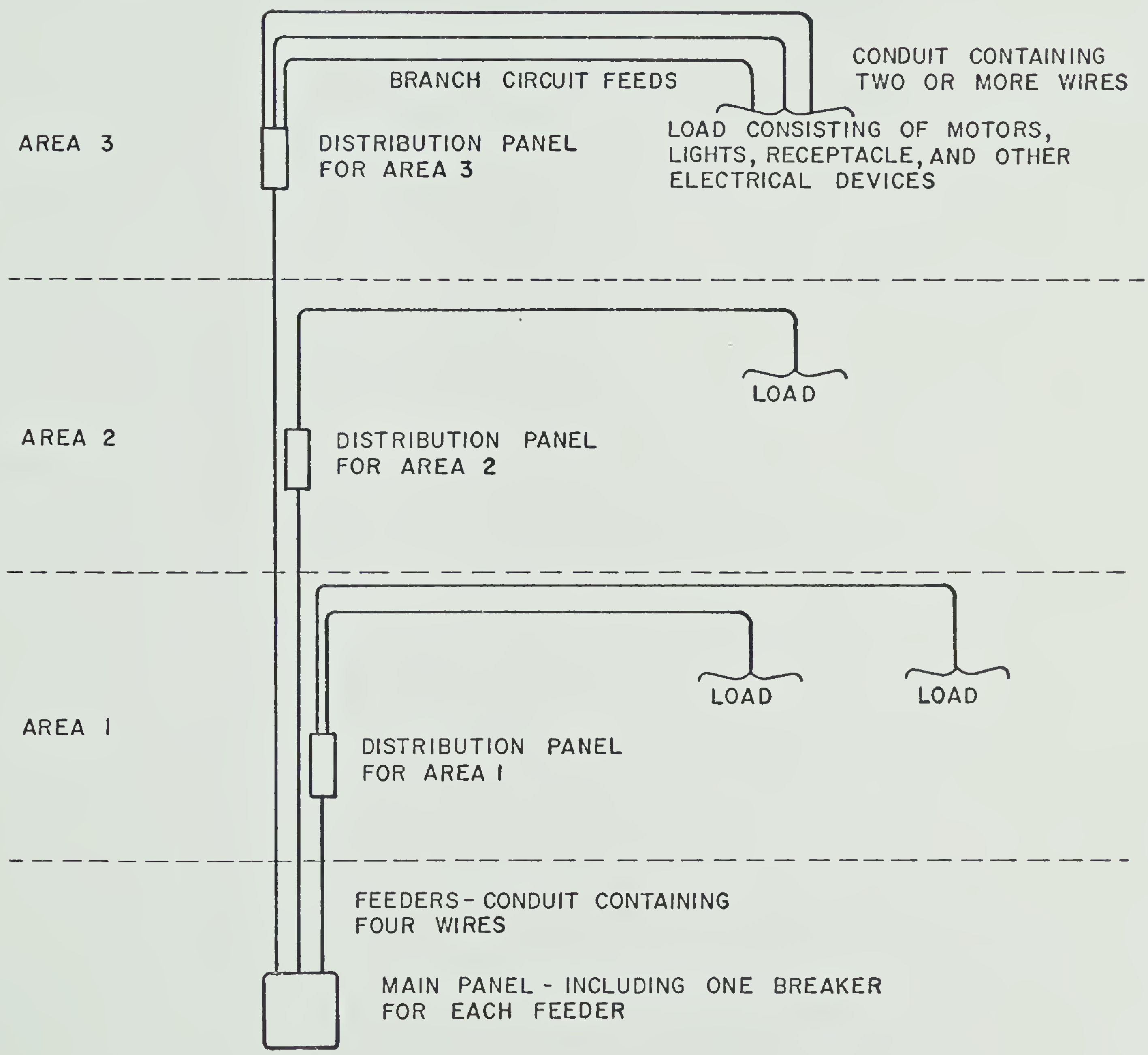
The model does not indicate, however, the best method of interconnecting the various electrical devices such as receptacles, lights, switches and motors in the building. The optimal distribution design is considered to be independent of the method of interconnecting electrical devices. The converse may not, however, be true.

The model presented in this thesis does not provide an analysis of the desirable state of other variables in the design such as spare capacity, location of main panel, number of blank spaces in panels, and voltage level of the system. These factors which certainly affect the construction cost of the distribution network are taken as "givens" or as exogenous variables to the model. Through sensitivity analysis the effects of the above variables on construction cost can be ascertained. Thus the model may provide an important step toward an analysis of the desirability of providing various features in a design.

The model used in this study is suitable for analysis of a three phase, four wire distribution system of voltage level 120/208 or 347/600 volts. The model is applicable only to wire

ILLUSTRATION - A

SIMPLIFIED POWER DISTRIBUTION NETWORK



and conduit type feeder networks and can be used as little more than a guide in designing a study of less common systems using bus duct feeders or armoured cable conductors. Other electrical systems commonly found in present day buildings such as fire alarm, communication, and central clock systems were not included in this study because of their highly varied circuit requirements.

CHAPTER II

SIMULATION AS A DECISION AID

What Simulation Is

Simulation in its broadest sense has been in existence since earliest time. Paintings and sculpture are a type of simulation. It is not readily apparent however that stone age man used the paintings on his cave walls as either planning, design or conceptual aids. Present day examples give a better insight into some of the functions of simulation. Consider wind tunnel tests of aircraft models, the jungle boat ride in Disneyland, planetarium shows, war games and link trainers.

The three basic types of models can serve as an aid to categorizing simulation. "A model may be loosely defined as a representation of a system."[1] Simulation is related to models in that all simulations require a model of some sort. Simulation is just one of many possible applications of models. Thus models need not be accompanied by simulation. The properties of models will become apparent shortly as the three types of models (a) iconic, (b) analogue and (c) symbolic are analyzed in detail.

Iconic models are physical representations in which the property of the system is represented by the same property in the model. They enable manipulation or aid conceptualization usually

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[1] J. W. Schmidt and R. E. Taylor, Simulation and Analysis of Industrial Systems (Georgetown, Ontario: Irwin-Dorsey Ltd., 1970), p.4.

because of a reduced size or simplification. Toy airplanes, link trainers, and Disneyland are examples of iconic models.

An analogue model, in contrast with the above, represents some property(ies) by a different property. A topographical map represents altitude by color variations. Maps, graphs and blueprints are also examples of this type of model.

A third type of model derives its name from its use of symbols. The characteristics of the symbolic model are best illustrated by examining its three forms: verbal, logical flow diagram and mathematical. In a verbal model properties of the system being represented are contained in the statements. Consider the following: "If Joe hits Jack and Jack has a stick, Jack will club Joe! If Jack does not have a stick he will utter obscenities and run away." It would be difficult to construct this model in either analogue or iconic form. The statements, as symbols of the system's properties aid us in planning related activities or in visualizing the system. A logical flow chart could attain the same description through a decision network or a chain of events. Flow charts in computer programming and charts of information flow in a company are examples of the logical flow chart form of the symbolic model. The mathematical form of the symbolic model is one of the most widely used and powerful models. A system described in mathematical terms can be analyzed, manipulated or delineated with the aid of the mathematical operations.

Mathematical models form the basis for numerous analysis

tools and decision making aids.[2] Simulation is one of these tools. Although simulation grew in scope with the advent of the electronic computer in the early 1950's, mathematical simulation is entirely possible without a computer.[3] Because numerous and repetitive calculations are often involved in a simulation, conditions in which an electronic computer is so ideally suited, the term simulation has come to imply simulation aided by a computer. It is this connotation of the term that will be meant whenever the term simulation is used in this study. Thus simulation will be defined as a study of a system with mathematical construct through a model analysis performed with the aid of a computer.

Types of Mathematical Simulation

Several classificatory systems exist for simulation models, however the most convenient and appropriate classifies models as deterministic, stochastic, static and dynamic.[4] It should be noted that these classifications are not all mutually exclusive.

In deterministic models neither the exogenous variables nor the endogenous variables are considered or treated as random

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[2]Many of these tools of analysis are contained under the heading of Operational Research Methods (See Wagner, Principles of Operations Research).

[3]Thomas H. Naylor, et al., Computer Simulation Techniques (New York: John Wiley and Sons Inc., 1966), p.1.

[4]Ibid., p.16.

variables.[5] The operating characteristics are assumed to be exact relationships rather than probability density functions. Similarly the mathematical relationships developed for the model are expressed as exact relations. This does not prevent one from trying several different values for inputs (ranging). A deterministic model is less demanding computationally than is a similar problem having random variables.

Stochastic models involve at least one operating characteristic which is given by a probability function. Analytical techniques for obtaining solutions to those types of problems are quite limited, hence much reliance is placed on simulation. Many economic and business situations are best described by this type of simulation model.[6]

Static models are those which do not take time variation into account and do not attempt to predict or simulate reactions over time. Most of the equilibrium type models such as those in economic theory are examples of static models. As well many of the optimizing tools in operations research are designed for

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[5]An endogenous variable of a model is the dependent variable. Exogenous variables are the independent or the input variables of the model. Thomas Naylor defines these terms in detail in Computer Simulation Techniques.

[6]Joe H. Mize and J. Grady Cox give several examples in Essentials of Simulation (Englewood Cliffs, N. J.: Prentice-Hall Inc., 1968).

static conditions. A static model may be used for different time frames by suitable adjustment of the exogenous variables but this would not constitute a dynamic model.

Dynamic models are mathematical models which deal with time varying interactions. Applications of simulation to dynamic systems include; simulation of the business cycle, queuing, scheduling, inventory models among others.[7] It is evident that models can be described in terms of either of the first pair of classifications combined with either of the second pair of classifications.

As it will be seen in later chapters this study directs itself to a situation fitting the classification of a deterministic static mathematical model. All the relationships formed will be exact and not subject to any random phenomena. The model will not attempt to predict time variations. Should any variation take place through time (i.e., such as costs, etc.) then the model will be adjusted through the exogenous variables.

Two other concepts relating to simulation are necessary for describing simulation with a dynamic model. These are: "next event logic" and "fixed time step" type models.[8] In dealing with

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[7] Jay W. Forrester gives several applications of this type of simulation in Principles of Systems (Cambridge, Massachusetts: Wright-Allen Press, 1968).

[8] These models are presented here only for completeness since the system under study, not being dynamic, does not involve these concepts.

dynamic simulations, since time is a factor, then some record must be made of the time when the simulated events are supposed to have taken place. In next event logic the events are processed an item at a time and the time for the next event or completion of a current event is calculated. The event is recorded and then the time is incremented by that amount calculated. This procedure ensures that items are dealt with in the proper order and events occurring nearly at the same time are not grouped into a segment of time and treated as if they occurred simultaneously. The importance of this varies with the type of problem. Unfortunately, this type of procedure may involve a prohibitively large amount of computer time. For this reason often a fixed time increment is employed and the increment size adjusted in proportion to accuracy and cost requirements.

Other facets of simulation are random number generation, probability distribution development and variance analysis which are involved in stochastic models.[9] These procedures often make use of pseudo-random number generators available with most computers and provide methods for generating probability distributions which may be required during the course of a simulation. As well sampling techniques have been developed to obtain variance or to reduce variance in selection. Monte Carlo simulation is an

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[9]These models are mentioned here for the sake of completeness. Further information can be obtained from Schmidt and Taylor, Simulation and Analysis of Industrial Systems or other operational research texts.

example of the latter.[10]

Rationale for Simulation

The basic reason for simulation, or for any other analysis, is of course a quest for knowledge. The rationale for simulation needs to be examined in the light of the objectives. These objectives may be classified as (1) the desire to describe a current system in order to gain insights into interactions, (2) to explore a hypothetical system, or (3) to design an improved system.[11] Thus if other methods are unavailable or provide insufficient information for an understanding of the system then one should simulate.[12]

A definition of simulation by J. H. Mize[13] indicates the prime and common reasons for simulating: "Simulation is the process of conducting experiments on a model of a system in lieu of either (1) direct experimentation with the system itself or (2) direct analytical solution of the problem associated with the system." Thus simulation becomes desirable in the following situations:[14]

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[10]Harvey M. Wagner, Principles of Operations Research with Applications to Managerial Decisions (Englewood Cliffs, N. J.: Prentice-Hall Inc., 1969), p.914.

[11]Ibid., p.892.

[12]Of course costs may be a consideration so that it becomes a decision based on amount of insight per dollar.

[13]Mize, Essentials of Simulation, p.1.

[14]Naylor discusses items 1, 2 and 3 in further detail in Computer Simulation Techniques, pp.5-8.

(1) It may be either impossible or extremely costly to observe certain processes in the real world. For example it would be virtually impossible to perform certain types of tests on the economy of the country, or similarly it would be very costly in terms of human lives for the United States to test all their theories with astronauts in outer space.

(2) The observed system may be so complex that it is impossible to describe it in terms of a set of equations for which analytical solutions exist. The mathematical relations for the system may contain noncontinuous functions for which no analytical techniques have as yet been developed.

(3) Although it may be conceptually possible to use a set of mathematical equations to describe the behavior of a system, they may be so complex that it may not be possible to obtain a straight forward solution to the problem or to make predictions about the system.

(4) Simulation may yield better conceptual insights regardless of whether or not the solution obtained is more or less accurate than other existing analytical tools.

The rationale for simulation is summed up by Harvey M. Wagner as being "the only game in town", because simulation can often be used when all else fails.[15]

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[15] Wagner, <u>Principles of Operations Research</u>, p.890.

Attributes of Simulation

The advantages of simulation can be examined by comparing them to the attributes of direct observation of real life and to the attributes of other analysis techniques. Several of the advantages of simulation over direct observation have been made apparent by the preceding section. Other advantages exist as well. Understanding may be enhanced because the simulation is completely repeatable and conditions including random selection do not change unless a change is explicity made. It will become apparent in later chapters of the ability to examine the model under many varied (but controlled) circumstances. The simulation is free from physical limitations which the system being studied may be subject to. This is made possible since the model is expressed in purely symbolic and logical terms. Simulation lends itself to the collection and processing of quantitative data and hence is a very powerful data processing system. Simulation may also be used as a pedagogical device for teaching basic skills in theoretical analysis. A time scaling advantage is an important aspect of simulation. Proceedings which in real life may take hours, days, weeks or years may be simulated in seconds. Finally, but not of least importance, simulation makes generalists out of specialists. Analysts are forced into an appreciation and understanding of all facets of the system, with the result that conclusions are less apt to be biased by particular inclinations. This list is by no means exhaustive and other advantages certainly exist in many

specific instances.[16] There are of course disadvantages. Firstly because natural phenomena are expressed in purely symbolic and logical terms the simulation is artificial. This in some cases requires considerable care to ensure that the model realistically represents the system and that results will be valid. Secondly, sometimes the model is inflexible and slight conceptual changes can result in drastic changes of the model and the computer simulation routine. Thirdly, simulation routines involve computational procedures and data which must be specific in great detail and completeness.

When comparing simulation to other analytical techniques the common tendency is to blame the technique for the complexities and unwielding properties of the system being analyzed. This is so because often simulation is used when no direct analytical technique exists for the solution of the problem. Partly for the above reason simulation models for computers are often very costly to construct and to validate. Special purpose simulation languages have been developed for the more common type of simulation, which help to reduce this factor. However, once constructed, the running of a simulation program can involve a great deal of costly computer time. It has been charged that the greatest single disadvantage of simulation lies in a fault of people. As people become more and more familiar with simulation they attempt to employ it in situations where other analytical techniques are better suited. "This is an

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[16] Naylor lists several additional advantages in Computer Simulation Techniques, pp.8-9.

insidious effect and it is easy to succumb."[17]

The previously mentioned ability for simulation to work when other techniques will not is of course an advantage. Very often this is due to the fact that fewer assumptions or requirements are required. Many techniques require either or both linearity of functions and continuity of functions. Simulation requires neither! A second advantage of simulation as compared to other techniques is its simplicity in concept. Although the end result may be complicated because of the large number of rules and regulations of the model, each relationship or operation when viewed separately may be entirely fathomable. Thirdly, simulations are often structured as a simplified copy of real life which accords them realism. A fourth advantage can be partly accrued to the third item. Simulation can be used for a completely different reason than for a direct analysis of a situation. Another class of simulation models tries to encompass goal-seeking or purposeful behavior. These models display what is termed "artificial intelligence".[18] Examples of such programs include computer routines for playing such games as chess, black-jack and checkers. There also have been some applications to managerial decisions. The purpose of simulation in these cases can be to

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[17] Schmidt and Taylor, Simulation and Analysis of Industrial Systems, p.6.

[18] Naylor, Computer Simulation Techniques, pp.23-41.

test theories of behavior by invoking in the computer the theorized behavior and then having the computer play the game. The results of the game can then be compared to games between two individuals. A similar group of simulation models, known as "heuristic programs" enable observation of action under so-called rules of thumb.[19]

It should be noted that simulation does not necessarily optimize automatically. This may be both an advantage and a disadvantage. Often refinement only is achieved through comparing results of simulations of various designs. This requires additional computer time and some individual effort but does yield more information than does straight forward prescription of optimality parameters.

Formulation of a Computer Simulation Experiment

There are nine steps in performing a simulation experiment which are generally accepted as a logical breakdown of procedure.[20] It is these steps, as detailed below, which have been utilized as a guide in the analysis of this study:

(1) Formulation of the problem. This formulation usually takes the form of (a) questions to be answered (b) hypothesis to be tested and (c) effects to be estimated. The initial statement may differ considerably from the final version because problem

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[19] Wagner, Principles of Operations Research, pp. 458, 918.

[20] Ibid., p.918.

interpretation is a sequential process that usually calls for continuous and progressive reformulation and refinement of the experimental objectives throughout the duration of the experiment. If a stochastic model is being used then the required statistical precision must be determined. Regardless of the type of model used it is desirable to specify the criteria for evaluating the degree to which the objectives are met.

(2) Collection and Processing of Data. This step does not necessarily take place all at once. In fact some information must be collected before the problem can be formulated while other information is added after the model is constructed and used.

(3) Formulation of the Mathematical Model. This procedure consists of (a) specification of the components, (b) specification of variables and parameters and (c) specification of functional relationships. This stage requires several checks and adjustments and perhaps the greatest amount of time. First the number of variables must be determined. Too many variables may conflict with the computer capabilities while too few may render the model invalid. Second the complexity of the model must be decided. Here a balance must be struck between an over simplified invalid model and an overly complex and conceptually difficult model which requires vast amounts of computation time. Thirdly, if the model is stochastic some attention may be warranted to utilizing special techniques to increase the computational

efficiency. Fourth, a check must be made for realism and validity. Does the model adequately describe the system of interest, and is it likely to give reasonably good predictions of behavior. Lastly, will the model be compatible with the type of experiments that are going to be carried out with it.

(4) Estimation of Parameters of Operating Characteristics. Depending upon the type of model this step may vary from direct utilization of available information to estimation by statistical techniques or inference of values from observation of behavior. This step transforms the previously developed general equations into relationships specifically for the problem at hand.

(5) Evaluation of the Model and Parameter Estimates. This step seeks to discover problems and errors before further time and cost is invested in the model. Various techniques are available to test different types of models.[21] If the model is stochastic, checks are made by statistical techniques and a check is made to ensure that the parameters are statistically significant. All models require checks to see if non pertinent variables are included or important variables omitted. A very useful procedure is to run through a mental simulation supported as required by hand calculations for a few possible combinations of conditions.

(6) Writing the Computer Program. A choice must be made at this stage. A selection must be made between a general

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[21] Naylor, Computer Simulations Techniques, pp. 35-37.

purpose language such as Fortran or one of the special purpose simulation languages such as GPSS, SIMSCRIPT, or GASP.[22] The special languages can be employed for the standard more common type of simulations for which they were developed. They can considerably shorten programming time but however often result in more computer running time than a general purpose language.[23] The general purpose languages offer the programmer the maximum flexibility.

(7) Validation. The objective here is simply that of verifying that the results of the simulation are a realistic representation. This may consist of simulation of a historical situation in which a comparison of results can be made or by verification through time by comparison with reality. In this study validation consisted of comparing model results with manual calculations.

(8) Design of Simulation Experiments. Because one of the advantages of simulation is the ease of repetitive analysis while exogenous variables are under control, insights can be gained through experimentation. The amount of experimentation to

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[22] Ibid., pp. 239-301.

[23] Ibid., p. 30.

be performed is a balance between value of the insights and costs in successive runnings of the model.

(9) Analysis of the Simulated Data. This last step involves viewing the data from the perspective of the theoretical construct and attempting to deduct answers to questions previously posed.

Since the various types of simulation cover a broad area, different simulations will require special considerations. Special applications are dealt with in further depth by Thomas H. Naylor,[24] J. H. Mize[25] and others.[26]

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[24] Ibid.

[25] Mize, Essentials of Simulation.

[26] As listed in the bibliography.

CHAPTER III

MODEL DESIGN

General Applicability

The model presented in this study was developed for a design characterized by the following:

(1) copper wire with x-link type insulation,

(2) circuit breaker type panels with breakers preinstalled,

(3) conduit requirements based on table 5A,[1]

(4) flush mounted distribution panels,

(5) EMT[2] conduit for requirements up to and including two inch and rigid steel thereafter,

(6) 347/600 volt distribution panels type "NFB"[3] with solid 225 amp mains,

(7) 120/208 volt distribution panels type NQB"[4], solid mains with 100 amp capacity for 30 circuits and smaller; 225 amp capacity for larger size tubes,

(8) type "CDP"[5] main panel, and

(9) building of poured concrete type construction with floor to floor heights of fifteen feet or less.

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[1] A supplement issued by The Alberta Electrical Protection Department which modifies Table 5 of the Canadian Electrical Code, pp. 359-360.

[2] Electrical Metallic Tubing.

[3] Canadian Westinghouse Co. Ltd. Identification of Panel Style.

[4] Ibid.

[5] Ibid.

Most of the above constraints can be revised to suit other designs simply by adjusting the unit cost data used as input to the computer model. Modification of items one to three inclusive would require minor program changes as well.

Systems of 120/208 volts or 347/600 volts can be analyzed without modification to the model developed in the study. To analyze a mixed voltage system having 120/208 volt loads with 347/600 volt feeders requires only a modification of the amperage calculation relation and inclusion of transformer costs in feeder cost data. The model cannot, however, be easily modified to handle systems having distribution panels of two voltage levels.

The computer program listing of the simulation model developed in this study is shown in illustration "G" in the appendix. Unless indicated otherwise references to "the model" in this paper refer to the above mentioned simulation model. The model is designed so that loads are only fed from panels on the same floor of the building thus the distribution costs of each floor are independent of the other floors.[6] To permit a comparison of some designs having loads fed from panels on other floors than the load is located a second computer model was developed.[7] This model

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[6] If costs for each floor are not independent then considering one panel only per floor of a five story building in which each panel can have nine different locations then the number of possible combinations is 9^5 or 387,420,489.

[7] This model can also serve an accounting function in combining results derived from the simulation model.

which will be referred to as "the manual trial model" is shown in illustration "H" in the appendix. The manual trial model differs from the basic model only in that rather than carrying an exhaustive search of a set of possible designs,[8] calculations are carried out only for designs specified in the input data.

General Design

The building to be analyzed is divided by a square or rectangular grid system on each floor so that all grid segments are of equal size and shape. Such a grid network permits specification of any point in the building by three integers representing X, Y, and Z coordinates in euclidean three dimensional space. Illustration B on the following page shows a hypothetical building with a grid system superimposed. The Z coordinate indicates the floor number. By assuming that all loads located within an area are fed from the center of the segment and similarly that panels are always located at the center of a segment the distances between loads and panels, as well as the panels and main panel can be easily calculated from the coordinates of each item. Once the distances are calculated required materials and corresponding costs are determined for all componenets of the distribution network. The model proceeds by systematically trying first one panel per floor located in one of the segments until all segments have

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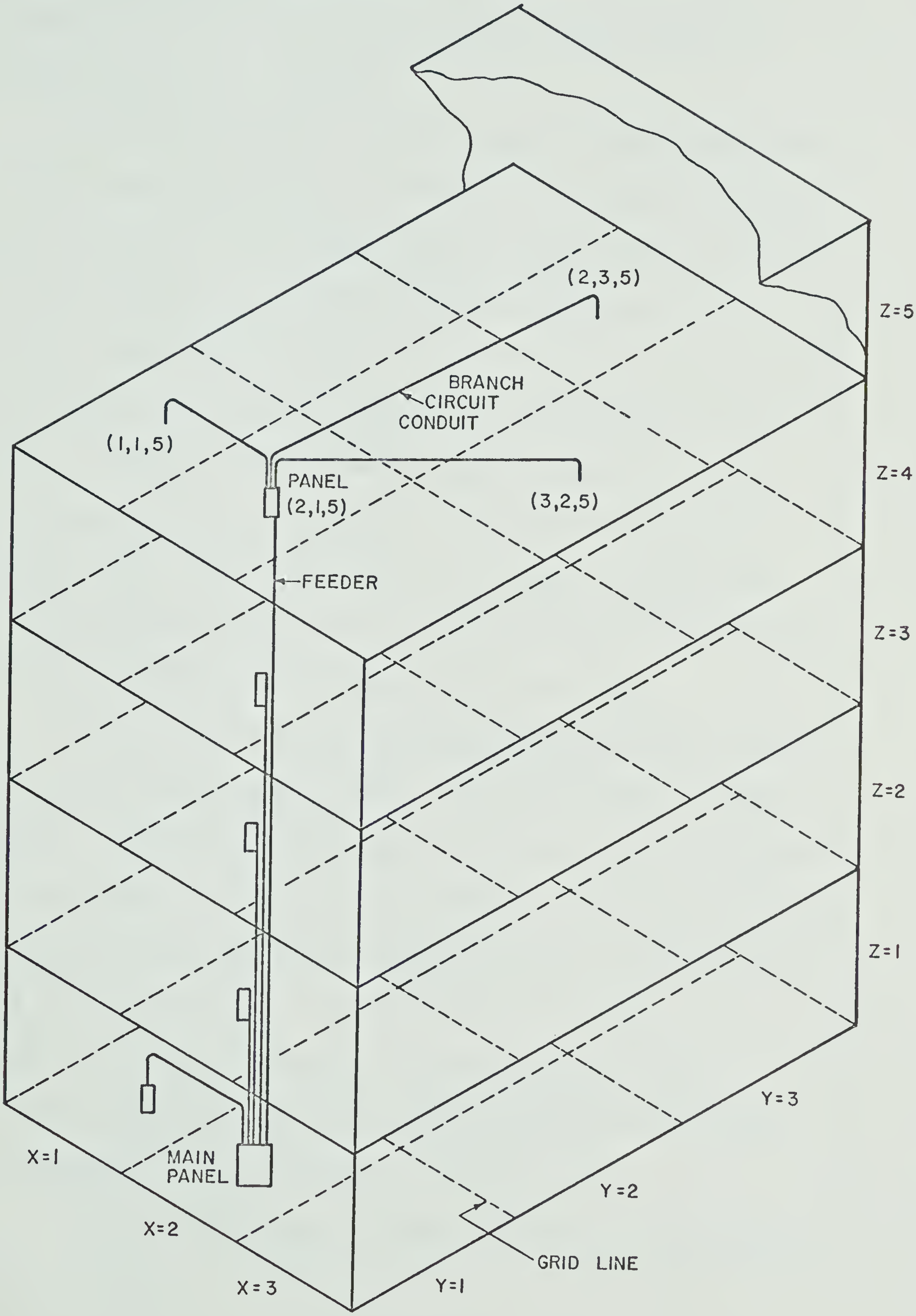
[8]The number of possible locations being determined by the grid network described in the following paragraph.

ILLUSTRATION - B

HYPOTHETICAL BUILDING AND PARTIAL DISTRIBUTION SYSTEM



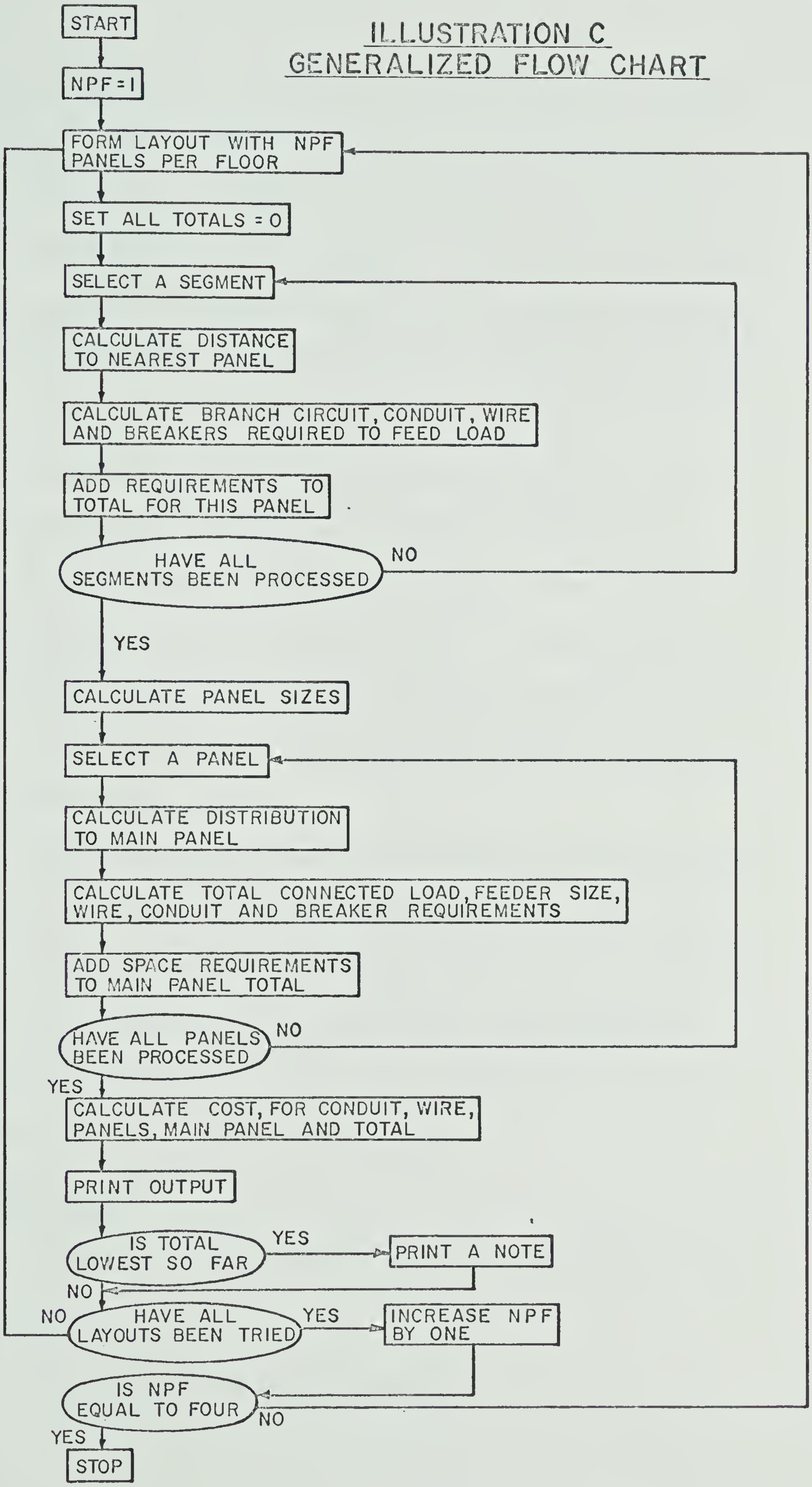
been tried and then with combinations of two and three panels. Illustration C on the following page shows a generalized flow chart of the simulation procedure.

Power requirements for each segment of the building are specified in the input data of the program. The model will also process "alternate source loads" which are loads which can equally well be fed from one of several locations. An example of an "alternate source load" is an exit light system which can be fed from any point in the conduit system which interconnects all the lights. In cases of equal distances from an "alternate source load" to various panels the load will be fed from the panel on the lowest floor. Other input data to the model includes dimensions of the segments, location of the main panel, permitted riser location points and unit costs for material and labor.

The grid system should be selected so that most segments contain loads of 3600 watts or more. This will enable the model to feed most loads with three phase circuits as is done in manually designed systems to reduce wire requirements. It is also desirable when possible to select the grid system so that the segments correspond to load divisions or natural building divisions. In buildings with repetitive layouts such as apartments proper selection of the grid network can reduce the amount of different load requirements to be specified.

The model calculates distances between any two segments

ILLUSTRATION C
GENERALIZED FLOW CHART



on a floor on the basis of being able to run diagonally between the segments.[9] This distance calculation can be modified to simulate conduit runs parallel with building lines by simply changing two statements of the program. The "manual trial model" which will handle designs with loads fed from a panel on another floor calculates distance on the basis of vertical feeds between floors.

The model operates in the opposite direction to the power flow within the building as indicated in the following example. The power flows from the main panel to the various distribution panels and then to the loads. The model operates by (1) processing each load segment in the building, (2) determining the required feeder sizes, and (4) determining the main panel requirements.

Costs are cumulated using the panels as costing centers thus retaining identity of the costs in terms of both location and nature of the incurrence. For example the cost for branch circuit wire for loads fed from each panel is provided by the model. Similarly cost for conduit from each panel is provided individually.

Mathematical Model

Much of the input data for the simulation model is in

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[9]See Illustration B on page 26.

table form. The terminology used in referring to this data is NAME (i, j) where "i" indicates the row number and "j" indicates the column number of the matrix or table called "NAME". The following are input parameters for the simulation model:

BCCOST (i, j)	=	Branch circuit conduit cost[10]
BWCOST (i, j)	=	Branch circuit wire cost[10]
C (i)	=	Special circuit breaker requirements[11]
FD (i, j)	=	Feeder cost data[12]
FSCHED (Q)	=	Schedule of allowable amperages of feeders[13]
LABOR	=	Labor rate for electrician
MPH (i)	=	Height requirements of breakers in main panel[14]
MX	=	Grid coordinate (x) of main panel
MY	=	Grid coordinate (y) of main panel
MZ	=	Grid coordinate (z) of main panel
PBCOST (i, j)	=	Panel breaker cost[15]
PTCOST (i, j)	=	Panel tub cost[15]

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[10] Refer to Table 1 which follows.

[11] Table 7 on page 41 indicates breaker sizes, i.e. C (9) is a 30-amp-2pole breaker.

[12] Refer to Table 3 which follows.

[13] Refer to Table 6 which follows.

[14] Refer to Table 5 which follows.

[15] Refer to Table 2 which follows.

RX_r	=	Grid coordinate (x) of riser r
RY_r	=	Grid coordinate (y) of riser r
SX	=	Dimension of grid segment in "X" direction
SY	=	Dimension of grid segment in "Y" direction
SZ	=	Height from floor to floor
VD (i)	=	Voltage drop[16]
VOLT 1	=	Line to neutral voltage (120 or 347)
VOLT 2	=	Line to line voltage (208 or 600)
WAT 1	=	Load in watts of general loads[17]
WAT 2	=	Load in watts for items fed from special breakers[17]
X	=	Grid coordinate of load segment
Y	=	Grid coordinate of load segment
Z	=	Grid coordinate of load segment

In addition to the above listed data the "manual trial model" requires the following:

PX_a	=	Grid coordinate (X) of panel "a"
PY_a	=	Grid coordinate (Y) of panel "a"
PZ_a	=	Grid coordinate (Z) of panel "a"
DEM (a)	=	Demand factor applicable to panel "a'

[16]Refer to Table 4 which follows.

[17]Required for every segment in the building.

TABLE I

BRANCH CIRCUIT COSTS

A. BRANCH CIRCUIT CONDUIT COSTS[1] - BCCOST (i, j)

	Size Inches	Material Cost[2] \$ per 100 ft.	Manhours per 100 ft.
i = 1	1/2	13.97	3.75
2	3/4	19.25	4.75
3	1	26.71	7.20
4	1 1/4	40.92	9.70
		j = 1	j = 2

B. BRANCH CIRCUIT WIRE COSTS[3] - BWCOST (i, j)

	Size #	Material Cost \$ per 1000 ft.	Manhours per 100 ft.
i = 1	12	49.30	0.8
2	10	67.60	1.1
3	8	118.00	1.3
4	6	173.00	1.5
5	4	239.00	1.7
6	3	339.00	1.9
7	14	40.00	0.7
		j = 1	j = 2

Notes: 1 Trade prices for E.M.T.

2 Includes cost of one connector every ten feet.

3 Trade prices for copper wire with RW-90-X-Link insulation.

TABLE 2

PANEL COSTS[1]

A. PANEL TUB COSTS[2] - PTCOST (i, j)

	Ckt. Capacity	$ - Material Cost 120/208v.	347/600v.	Labor Manhours[3]
i = 1	12	70	62	1.1
2	18	70	62	1.2
3	24	70	62	1.3
4	30	70	62	1.4
5	36	70	62	1.5
6	42	70	62	1.6
7	48	140	124	2.8
8	60	140	124	2.9
9	72	140	124	3.1
10	84	140	124	3.4
11	126	210	186	5.8
		j = 1	j = 2	j = 3

B. PANEL BREAKER COSTS - PBCOST (i, j)

	Breaker Size	$ - Material Cost 120/208v.	347/600v.	Labor Manhours[4]
i = 1	15A.-S.P.	2.50	11.00	.62
2	15A.-2P.	9.00	48.50	.97
3	15A.-3P.	24.50	62.00	1.32
4	20A.-S.P.	2.50	11.00	.70
5	20A.-2P	9.00	48.50	1.13
6	20A.-3P.	24.50	62.00	1.56
7	30A.-S.P.	2.50	11.00	.87
8	30A.-2P.	9.00	48.50	1.45
9	30A-3P.	24.50	62.00	2.03
10	40A-2P.	9.00	48.50	1.63
11	40A.-3P.	24.50	62.00	2.26
12	50A.-3P.	24.50	62.00	2.49
13	70A-3P.	29.50	73.50	3.11
14	100A-3P.	32.50	73.50	4.20
15	Blanks	0.50	4.50	0.00
		j = 1	j = 2	j = 3

Notes:
1. Trade prices for flush mounted panel.
2. Based on 225 amp mains.
3. Mounting including fastening to block or stud wall.
4. For dressing wire, connecting to breaker, and portion of conduit connection to panel.

TABLE 3 FEEDER COSTS FD (i, j)

SIZE			MATERIAL COSTS $				LABOR - MANHOURS			
Wire Size #	Breaker Amps	Conduit Inches	Wire/ 1000 ft.	Breaker Each	Conduit /100 ft.	Fixed Costs	Wire/ 100 ft.	Connec- tions	Conduit /100 ft.	Fixed Costs
14	20	1/2	40.60	62.00	13.97	0	.50	3.0	2.5	.18
12	30	1/2	49.30	62.00	13.97	0	.60	3.0	2.5	.18
10	40	3/4	67.60	62.00	19.25	0	.80	3.0	3.0	.26
8	50	1	118.00	62.00	26.71	0	1.00	3.0	4.0	.30
6	70	1 1/4	173.00	74.00	40.92	6.04	1.30	4.2	5.5	.60
4	90	1 1/4	239.00	74.00	40.92	6.04	1.60	4.2	5.5	.60
3	100	1 1/4	339.00	74.00	40.92	6.04	1.65	7.2	5.5	.60
2	125	1 1/2	388.00	173.00	52.15	7.68	1.75	7.2	6.0	.75
1	150	2	442.00	173.00	67.35	11.30	2.0	7.2	6.5	.90
2/0	200	2	690.00	173.00	67.35	11.30	2.85	10.2	6.5	.90
3/0	225	2	858.00	173.00	67.35	11.30	3.40	10.2	6.5	.90
4/0	250	2 1/2	1037.00	340.00	201.15	28.55	3.60	10.2	16.0	2.40
250	300	2 1/2	1274.00	340.00	201.15	28.55	3.90	10.2	16.0	2.40
350	350	3	1697.00	340.00	276.82	42.78	4.45	10.2	19.0	2.80
500	400	3 1/2	2278.00	340.00	373.28	69.59	5.20	16.2	22.0	3.20
			1	2	3	4		5		4

Notes:
1. Based on copper wire with RW-90-X-Link insulation.
2. FA, JA, LA frame breakers preinstalled in "CDP" panel (suitable to 600 volts).
3. Prices include couplings; based on E.M.T. up to and including two inch.
4. Prices include 3 elbows, 2 connectors (or bushings and locknuts) for each feeder.
5. For dressing wires and connecting to lugs at both ends; installing conduit connectors.

TABLE 4 - VOLTAGE DROP VD (i)

For: copper wire in magnetic conduit

	Wire Size	Voltage Drop[1]
i = 1	14	2.770
2	12	1.775
3	10	1.105
4	8	.700
5	6	.461
6	4	.300
7	3	.250
8	2	.198
9	1	.161
10	2/0	.110
11	3/0	.091
12	4/0	.076
13	250 MCM	.068
14	350 MCM	.055
15	500 MCM	.045

TABLE 5 - MAIN PANEL BREAKER HEIGHTS[2] MPH (i)

	Breaker Size - Amps	Height - Inches
i = 1	20	4.12
2	30	4.12
3	40	4.12
4	50	4.12
5	70	4.12
6	90	4.12
7	100	4.12
8	125	5.50
9	150	5.50
10	200	5.50
11	225	5.50
12	250	8.25
13	300	8.25
14	350	8.25
15	400	8.25

1. Voltage drop line to neutral 3P-4 wire per 10,000 amp feet.

2. Westinghouse type CDP breakers.

TABLE 6

FEEDER SCHEDULE - FSCHED(Q)

	Nominal Size of Breaker[1]	Allowable Amperage[2]
Q = 1	20	16
2	30	24
3	40	32
4	50	40
5	70	56
6	90	72
7	100	80
8	125	100
9	150	120
10	200	160
11	225	180
12	250	200
13	300	240
14	350	280
15	400	320

1. This column is not a part of data, for information only.
2. Based on 80% loading <u>Canadian Electrical Code</u> Part I Section 8036.

The following parameters are calculated by the model[18]:

PTOT (a, j) = Table of totals for panels where:

a = panel number or row of table[19]

j = 1, 15 for breaker requirements

j = 16 for connected load in watts

j = 17,23 for totals of various wire sizes fed from panel

j = 24,27 for totals of various size conduits fed from panel

PSIZ (a, j) = Table of panel data where:

a = panel number or row of table[19]

j = 1 for number of active circuits

j = 2 for number of spares

j = 3 for tub size

j = 4 for number of blanks

j = 5 for feeder reference size number (Q) before voltage drop adjustment if any

j = 6 for total length of feeder conductors

j = 7 for conduit length

j = 8 for design load for panel

j = 9 for feeder references size number (Q) after voltage drop adjustment if any

PCOST (a,j) = Table of costs for panels, feeders and branch circuitry fed from each panel where:

a = panel number or row of table[19]

---

[18] Illustration D on page 50 shows an example of the output data.

[19] For convenience the output from the program illustrates the location of each panel in the design.

j = 1 for branch circuit conduit cost

j = 2 for branch circuit wire cost

j = 3 for panel cost

j = 4 for feeder wire cost

j = 5 for feeder conduit cost

j = 6 for breaker and connections cost

j = 7 for total of all above

CFMP = Cost for mounting main panel distribution tub.

TCOST = Total cost for distribution network.

MCWAT = Total connected loads in watts

MDWAT = Total design load in watts.[20]

The equations used to calculate the above parameters are indicated below.

Symbols used:

D1 = Basic distances from load to nearest panel.

DISTa = Basic distance from main panel to panel "a".

N3PH = Number of three phase circuits composing NBC.

NBC = Number of fifteen amp circuits required to feed loads composing WAT1 total.

NCON1 = Number of 1/2 inch conduit runs to segment

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[20]Design load is defined here as the total of the connected loads for each panel times assigned demand factor for each panel.

NCON2	=	Number of 3/4 inch conduit runs to segment.
NCON3	=	Number of 1 inch conduit runs to segment.
NCON4	=	Number of 1 1/4 inch conduit runs to segment.
NP	=	Number of panels in design.
NSP	=	Number of wires required for single phase circuits composing NBC.
NW1	=	Number of size 12 conductors required to segment.
NW7	=	Number of size 14 conductors required to segment.

Equations:

(1) D1 = Min over all a of

$$\left[SZ \times [Z-PZ_a] + \sqrt{[SX \times [X-PX_a]]^2 + [SY \times [Y-PY_a]]^2}\right]$$

see note[21]

(2) A = Value of "a" when above minimum occurs.

(3A)* NBC = WAT1/1200 when voltage=120/208

(3B)* NBC = WAT1/3500 when voltage=347/600

*rounded to next highest integer

(4) C1A = C(1)

(5) C(1) = C(1) + NBC

(6) N3PH = NBC/3 fraction truncated

(7) NSP = [NBC - (3 x N3PH)] + 1

---

[21]For "alternate source loads" the minimum is taken over all grid paints within the range specified.

(8A) NW1 = [4 x N3PH] + NSP + [2 x C1A]

+[3 x C(2)] + [4 x C(3)]+ [2 x C(4)]

+[3 x C(5)] + [4 x C(6)] + 2 x C(7)]

+ [2 x C(8)] when voltage=120/208

(8B) NW1 = [2 x C(7)] + [3 x C(8)] when voltage=347/600

(9A) NW7 = 0 when voltage=120/208

(9B) NW7 = [4 x N3PH] + NSP + [2 x C1A] + [3 x C(2)]

+ [4 x C(3)] + [2 x C(4)] + [2 x C(5)]

+ [4 x C(6)] when voltage=347/600

Refer to Table 7 on the following page for a summary of schedule for wire and conduit.

Above parameters calculated for every load segment.

(10) PTOT(A,k) = $\sum_{LS}$[C(k)] for k = 1, 14 see note[22]

(11) PTOT(A,16)= $\sum_{LS}$[[WAT1 + WAT2] x DEM(A)]

(12) PTOT(A,17)= $\sum_{LS}$[[D1 + 12] x [NW1 + [2 x C(9)]]]

(13) PTOT(A,18)= $\sum_{LS}$[[D1 + 12] x [[3 x C(10)] + [4 x C(11)]]

(14) PTOT(A,19)= $\sum_{LS}$[[D1 + 12] x 4 x C(12)]

(15) PTOT(A,20)= $\sum_{LS}$[[D1 + 12] x 4 x C(13)]

(16) PTOT(A,22)= $\sum_{LS}$[[D1 + 12] x 4 x C(14)]

---

[22] $\sum_{LS}$ Indicates summation over all load segments. All parameters defined by preceding relations are defined for each load segment.

TABLE 7

CONDUIT AND WIRE SCHEDULE

BREAKER		WIRE		CONDUIT	
Size	Symbol	Size	Cond. Req'd.	Size	Symbol
100A-3P	C(14)	3	4	1 1/4	CON4
70A-3P	C(13)	6	4	1 1/4	CON4
50A-3P	C(12)	8	4	1	CON3
40A-3P	C(11)	10	4	3/4	CON2
40A-2P	C(10)	10	3	1/2	CON1
30A-3P	C(9)	12	4	1/2	CON1
30A-2P	C(8)	12	3		
30A-1P	C(7)	12	2		
20A-3P	C(6)	12[1]	4		
20A-2P	C(5)	12	3	Based on total number of conductors - see Table 8	
20A-1P	C(4)	12	2		
15A-3P	C(3)	12	4		
15A-2P	C(2)	12	3		
15A-	C(1)	12	2		

1. Size 14 wire is used for 15 and 20 amp circuits when voltage is 347/600 volts. At lower voltages voltage drop limits require many runs to be a minimum of size 12. Because of cost of (1) calculating voltage drop (2) specifying sizes on documents and (3) field control, industry has adoped the practice of using a minimum of size 12 on 120/208 volt systems in commercial buildings. This model could be used to test the potential benefits of using size 14 on 120/208 volt systems.

TABLE 8

GENERAL BRANCH CIRCUIT CONDUIT SCHEDULE

Size #12 Conductors		Size #14 Conductors	
Number	Conduit	Number	Conduit
16	2-CON2	12-18	CON3
10-15	CON3	7-11	CON2
6-9	CON2	1-6	CON1
1-5	CON1		

(17) $PTOT(A,23) = \sum_{LS} [[D1 + 12] \times NW7]$

NCON1, NCON2, NCON3 are determined from schedules listed in Tables 7 and 8 (pages 41 and 42) for each load segment.

(18) $PTOT(A,24) = \sum_{LS} [[D1 + 7] \times [NCON1 + C(10)]$

(19) $PTOT(A,25) = \sum_{LS} [[D1 + 7] \times [NCON2 + C(11)]$

(20) $PTOT(A,26) = \sum_{LS} [[D1 + 7] \times [NCON3 + C(12)]$

(21) $PTOT(A,27) = \sum_{LS} [[D1 + 7] \times [C(13) + C(14)]$

(22) $PSIZ(a,1) = \sum_{n=1,14} [F \times PTOT(a,n)]$ for $a = 1,2...NP$

where $F = 1$ for $n = 1, 4, 7$

$F = 2$ for $n = 2, 5, 8, 10$

$F = 3$ for $n = 3, 6, 9, 11, 12, 13, 14$

(23) $PSIZ(a,2) = 0.1 \times PSIZ(a,1)$ for a=1,2....NP fraction truncated

(24) $PSIZ(a,3) = [[1.2 \times PSIZ(a,1)] + PSIZ(a,2)]$ for a=1, NP rounded to next higher number 12, 18, 24, 30, 36, 42, 48, 60, 72, 84, 120

(25) $PSIZ(a,4) = PSIZ(a,3) - PSIZ(a,2) - PSIZ(a,1)$ for a=1,NP

(26) $PTOT(A,15) = PSIZ(a,4)$ for a = 1, NP

(27) $PSIZ(a,8) = PTOT(a,16)/(3 \times \text{Volt } 2 \times .85)$ for a = 1, NP

(28) $PSIZ(a,5) = MIN[i]$ which satisfies $FSCHED(i) \geq PSIZ(a,8)$

(29A) $$DIST_a = \left|SZ \times (MZ - PZ_a)\right| + \sqrt{[SX \times (MX - PX_a)]^2 + [SY \times (MY - PY_a)]^2}$$

when risers are unrestricted

(29B) $$DIST_a = \underset{\text{over all } r}{\text{Min}} \left[\left|SZ \times (MZ - PZ_a)\right| + D1 + D2\right]$$

when riser locations are restricted

where:

$$D1 = [SX \times (MX - RX_r)]^2 + [SY \times (MY - RY_r)]^2$$

$$D2 = [SX \times [PX_a - RX_r]]^2 + [SY \times [PY_a - RY_r]]^2$$

(30) $PSIZ(a,6) = [DIST_a + 6] \times 4$

(31) $PSIZ(a,7) = DIST_a$

$PSIZ(a,9) = MAX[PSIZ(a,5),[MIN(i)$ such that $VDROP(i) \geq VDMAX]]$

where: $VDROP(i) = VD(i) \times DIST_a \times PSIZ(a,8)/10000$

$VDMAX = .03 \times VOLT1$

(32) $$PCOST(a,1) = \sum_{j=1}^{4} [[BCCOST(j,1)/100] + [BCCOST(j,2) \times LABOR/100]$$

(33) $$PCOST(a,2) = \sum_{j=1}^{7} [[BWCOST(j,1)/1000] \times [PTOT(a,j + 16)]$$

(34) $$PCOST(a,3) = PTC(j, k) + [PTC(j, 3) \times LABOR] + \sum_{1=1}^{15} [[PBC(1, k) + [LABOR \times PBC(1,3)]] \times PTOT(a,1)] + [PSIZ(a,2) \times PBC(1, k)]$$

where: $k = 1$ for 120/208 volts

$k = 2$ for 347/600 volts

$j = [PSIZ(a,3)/6] - 1$ for $PSIZ(a,3) \leq 48$

$j = 8, 9, 10, 11$ for $PSIZ(a,3) = 60, 72, 84, 120$ respectively

(35) $$PCOST(a,4) = [[FD(m,4)/1000 + [LABOR \times FD(m,8)/100]] \times PSIZ(a,6)$$

(36) $PCOST(a, 5) = FD(m,7) + [LABOR \times FD(m,11)]$

$+ [[FD(m,6)/100] + [LABOR \times FD(m,10/100]]$

$\times PSIZ(a,7)$

where: $m = PSIZ(a,9)$

(37) $PCOST(a,6) = FD(Q,5) + [FD(Q,9) \times LABOR]$

where: $Q = PSIZ(a,5)$

(38) $$PCOST(a,7) = \sum_{j=1}^{6} PCOST(a,j)$$

(39) $$CFMP = \sum_{a=1}^{NP} [LABOR \times FD(Q,9)/2]$$

where: $Q = PSIZ(a,5)$

(40) $$TCOST = CFMP + \sum_{a=1}^{NP} \sum_{j=1}^{6} PCOST(a,j)$$

(41) $$MDWAT = \sum_{a=1}^{NP} [PTOT(a,16)]$$

(42) $$MCWAT = \sum_{LS} [WAT1 + WAT2]$$

(43) $$MAMPS = \sum_{a=1}^{NP} [PSIZ(a,8)]$$

The total cost derived above does not include material cost for the main breaker and main panel distribution tub. These costs are independent of the distribution design and thus will not affect the selection of a minimum cost design from the designs simulated. Inclusion of these costs would require specification

of a table of costs relating material costs to total design amps and a minor program change. Such a table of costs would depend upon potential short circuit current.

Unit Costs

The cost calculations performed by the model are simply applications of the unit cost for each item used to the quantity of the item calculated in the preceding stages. The unit costs used in this study are summarized in Tables 1, 2 and 3 in the preceding section.

All material prices used in this study are based upon trade pieces as quoted in Westinghouse catalogues.[23] Labor manhour figures were derived from "How to Estimate Electrical Work",[24] "Estimating for Profit",[25] and "Electrical Estimating",[26] and were adapted for the specific purpose at hand by the writer in discussion with various personnel in the estimating field.[27] Labor units and material prices are likely to vary for different locations,

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[23] Westinghouse Calculator (Canadian Westinghouse Co. Ltd., 1970), and Westinghouse Quick Selector (Canadian Westinghouse Co. Ltd., 1970).

[24] How to Estimate Electrical Work (New York: Electrical Construction and Maintenance Association, n.d.).

[25] Estimating for Profit (Edmonton, Alberta: Electrical Contractors Association of Alberta, n.d.).

[26] Ray Asley, Electrical Estimating (New York: McGraw-Hill, 1961, 3rd ed.).

[27] Primarily representatives of Allsop-Morgan Engineering Ltd.

situations and type of construction. The ease by which the unit costs can be changed permits users of the model to use units which they feel to be most applicable.[28]

The analysis of cost for the distribution network is broken down into:

(1) branch circuit costs (wire and conduit),

(2) panel costs (breakers and tub),

(3) feeder costs (wire, conduit and breakers), and

(4) main panel distribution tub.

Fixed and variable costs are separated in all cases so that the units can be meaningfully applied to a wide variety of situations. On very large projects however, material costs may have to be adjusted to reflect large volume buying prices.

Table 1 on page 32 illustrates the branch circuit wiring and conduit costs used in this study. The following example indicates how the table figures were derived:

	Material	Labor Manhours
1/2" E.M.T. per 100 feet	11.30	3.50
Couplings 10 per 100 ft. @ $16.20/C	1.62	-
Straps or fasteners 20 per 100 ft.	.86	-
Screws or clips 20 per 100 ft.	.19	.25
	$13.97	$ 3.75

[28]A labor rate of $5.55 was used in this study.

There is no allowance for connectors in the above example since the number of connectors is independent of the length of the run. The number of connectors required in a building is independent of the layout of the distribution network. Thus, ignoring the cost of connectors will not affect the relative costs of the distribution networks simulated. The cost of connectors is small in relation to the other conduit costs[29] not included in the model and thus exclusion of these costs will not affect the feasibility of using the model as a part of a larger program to estimate total electrical costs for a building.

Feeder costs include wire, conduit, breaker and connection costs for the wire and conduit.[30] Labor units for conduit are developed in the same manner as branch circuit conduit. Labor units are smaller than those for branch circuit conduit because of the larger unobstructed runs normally encountered with feeders. The units for fixed costs are based upon three elbows plus two connectors or two bushings with locknuts per run.

The allowance made for installation of the main panel

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[29]Costs for interconnecting wiring devices.

[30]Refer to Table 3 on page 34.

distribution tub is based upon the number and size of breakers contained therein. The rationale for such an allowance is that installation costs will vary with the weight of the panel. The allowance used for each breaker is shown in Table 9 below.

TABLE 9

MAIN PANEL INSTALLATION COSTS

Breaker Size Amps	Labor Allowance Manhours
15 - 50	1.5
70 - 90	2.1
100 - 150	3.6
200 - 350	5.1
350 - 500	8.1

Printout of Results

The information provided by the simulation model for each trial design is shown in illustration "D" on the following page. The manual trial model provides a list of the panels, locations and demand factors used in the design in addition to the information shown in illustration D.

An abbreviated output consisting of the list of panel locations and total cost printed on a single line was found to expedite the analysis of the many designs tried by the model. A user is cautioned against performing an analysis based upon an abbreviated output only since errors due to incorrect data or

ILLUSTRATION - D
SAMPLE OUTPUT

FEEDER SCHEDULE

LOCATION	AMPS	LENGTH	WIRE SIZE	
2, 1, 1	59	0.0	4	IN A 11/4 INCH COND
2, 3, 1	227	95.33	250	IN A 21/2 INCH COND
2, 1, 2	168	12.00	3/0	IN A 2 INCH COND
3, 2, 3	106	82.17	1	IN A 2 INCH COND
2, 3, 4	142	131.33	2/0	IN A 2 INCH COND
2, 2, 5	142	95.67	2/0	IN A 2 INCH COND

TABLE OF PANEL TOTALS

PANEL	15 SP	15 2P	15 3P	20 SP	20 2P	20 3P	30 SP	30 2P	30 3P	40 2P	40 3P	50 3P	70 3P	100 3P	BLANK	WATTS	WIRE TOTALS 12	10	8	6	4	3	14	BRANCH CKT CONDUIT 1/2	3/4	1	1-1/4
2, 1, 1	16	0	0	0	0	0	0	0	0	0	0	0	0	0	7	18100	884	0	0	0	0	0	0	80	87	0	0
2, 3, 1	42	0	3	0	0	0	0	0	0	0	0	1	0	0	13	69600	3758	0	181	0	0	0	0	141	328	105	0
2, 1, 2	44	0	0	0	0	0	0	0	0	0	0	0	0	0	12	51700	3197	0	0	0	0	0	0	0	476	0	0
3, 2, 3	23	0	2	0	0	0	0	0	0	0	0	0	0	0	5	32700	1233	0	0	0	0	0	0	18	105	31	0
2, 3, 4	37	0	0	0	0	0	0	0	0	0	0	0	0	0	8	43500	2386	0	0	0	0	0	0	52	331	0	0
2, 2, 5	37	0	0	0	0	0	0	0	0	0	0	0	0	0	8	43500	2612	0	0	0	0	0	0	7	385	0	0

TABLE OF PANEL SIZE INFORMATION

PANEL	CIRCUITS	SPARES	TUB SIZE	BLANKS	REF1 SIZE	FEEDER LENGTH	CONDUIT LENGTH	DESIGN LOAD	REF2 SIZE ADJ FOR VOLT DROP
2, 1, 1	16	1	24	7	6	24	0	59	6
2, 3, 1	54	5	72	13	13	405	95	227	13
2, 1, 2	44	4	60	12	11	72	12	168	11
3, 2, 3	29	2	36	5	9	352	82	106	9
2, 3, 4	37	3	48	8	10	549	131	142	10
2, 2, 5	37	3	48	8	10	406	95	142	10

TABLE OF COSTS

PANEL	BRANCH COND	BRANCH WIRE	PANEL COST	FEEDER WIRE	FEEDER CONDUIT	BREAKER&CONN	
2, 1, 1	67.51	82.83	178.27	7.87	9.37	97.31	443.16
2, 3, 1	268.66	386.54	559.52	603.63	317.32	396.61	2532.28
2, 1, 2	217.12	299.56	433.50	75.36	28.71	229.61	1283.85
3, 2, 3	74.82	115.53	286.12	194.66	101.10	212.96	985.19
2, 3, 4	169.06	223.57	386.86	465.65	151.78	229.61	1626.53
2, 2, 5	178.04	244.74	386.86	344.36	114.55	229.61	1498.16

MAIN PANEL TUB MOUNTING COST 144.85 NO. OF TUBS REQD 1.
TOTAL COST IS 8513.99

ADD MATERIAL COST FOR MAIN PANEL TUB(S)

TOTAL CONNECTED LOAD; 259100 WATTS

OESIGN LOAD; 259100 WATTS

OESIGN AMPS; 844

application could be overlooked. In addition, the more complete printout may provide the basis for insights into the nature of cost occurrence in the building under study.

CHAPTER IV

TESTING THE MODEL

The model presented in this study was validated and refined by comparing computer results with hand calculations performed for for a hypothetical building. Considerably more printout information was provided by the model during this stage than was outlined in the previous chapter, in order to facilitate checking. This procedure is suggested whenever modifications are made to the model.

The Building

The building used for analysis is shown in illustration "E" on the following page. The parameters of the building and the electrical requirements are listed below:

Building	5 stories (including basement) height 60 feet floor dimensions 100' x 143'
Electrical	average load 3 watts/square foot voltage 120/208 roughly uniform load distribution (4700 watts/segment)
Grid	nine segments (47.67' x 33.33') per floor

The load requirements for each segment are summarized in Table 10 below.

ILLUSTRATION - E
TEST BUILDING

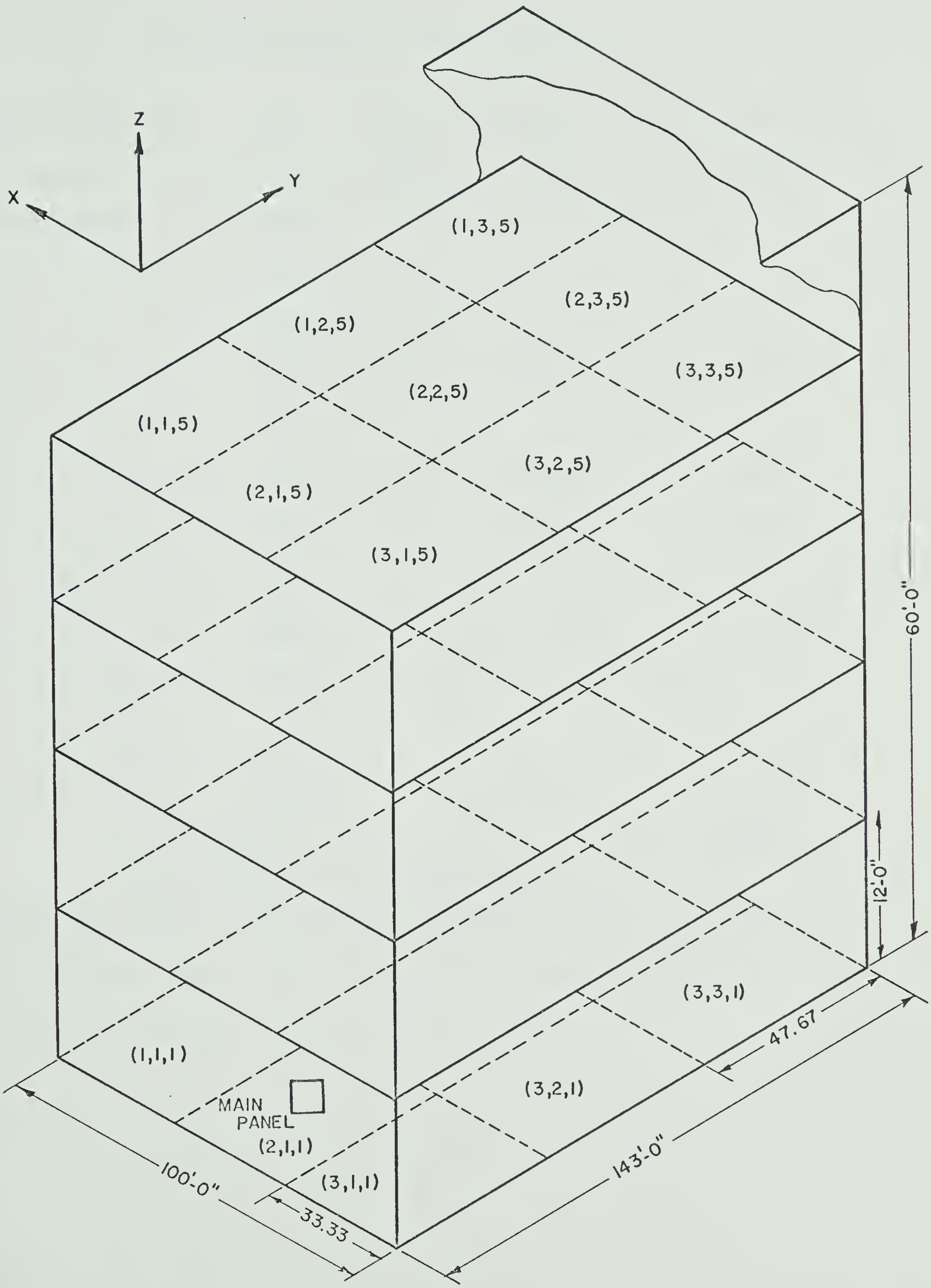

TABLE 10

LOAD REQUIREMENTS IN TEST BUILDING

Segment Coordinates[1]			Wat1	Special Breakers		Wat2
X	Y	Z	Watts	Number	Size	Watts
Every segment			4700			
1	1	1	2000			
3	1	1	2000			
1	2	1	2000	3	15A-3P	9000
2	2	1	2000			
3	2	1	2000	2	15A-3P	6000
1	3	1	2000	1	50A-3P	13000
2	3	1	2000			
3	3	1	2000			
1-3	2-2	2-2	1200			
1-1	2-3	3-3	1200			
2-2	2-2	1-5	1200			
			Total = 231,100			Total = 28,000

Total connected load = 259,100 watts

[1] Hyphenated numbers indicate alternate source loads, i. e. (1-3, 2-2, 2-2) indicates load can be fed from segments (1,2,2) or (2,2,2) or (3,2,2).

The loads are roughly uniform in distribution except in the basement, thus resembling an office building in electrical characteristics. An evenly distributed load on several floors allowed analysis of the effects of the location of the main panel upon the location of panels to achieve a minimum cost design.

Tests Performed

The simulation model was used to search for the best[1] locations for one, two and three panels per floor. The simulation model operates by trying different layouts by moving the panels on all floors simultaneously. The preferred locations for panels on the various floors did not all occur in the same trial. Thus the "manual trial model" was used to combine the solutions indicated for the various floors into one tableau. Based upon the preferrable layout for three panels per floor a design was tested using four panels per floor.

The above tests represent a fairly extensive analysis of the standard situation where loads are fed only from panels on the same floor. If this constraint is relaxed the number of design possibilities becomes larger than can be handled by the computer. The "manual trial model" was used to test several intuitively desirable layouts as well as some extreme designs. The costs

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[1] Best of the nine locations per floor permitted by the choice of a grid system.

associated with the designs were determined for the following design rules:

(1) Loads fed from the nearest panel.

(2) Loads fed from the nearest panel on the same or lower floor.

(3) Loads fed from the nearest panel on the same floor (where feasible since some of the designs did not have panels on all floors).

Constraint number two above was included to test the validity of the theory that: "a load should never be fed from a lower panel since this involves running the feeder beyond the load to the panel and then back to the load." Constraint number three was included for comparison only since the simulation model tested such designs previously.

CHAPTER V

RESULTS AND CONCLUSIONS

Test Results

The results obtained from the tests described in Chapter IV are summarized in Table 11 on the following page. An interesting finding is that the lowest cost obtained was for the design consisting of nine panels located on the first floor. This result is only valid however if walls exist near the center of each of the nine segments where the panels and vertical conduit runs can be located. Rarely would such a design be desirable even if feasible unless the cost savings were large.

Conclusions

The following conclusions are drawn from an analysis of the data presented in Table 11:

Expected:

(1) Costs are fairly sensitive to the location of panels ranging from $8,589.94 to $12,237.00.[1]

Unexpected:

(1) Costs are not always minimized by locating a panel in the center of the area to be served.

(2) Costs are relatively insensitive to the number of panels in an area. In the example costs were $8,589.94, $8,175.70, and $8,126.00 for one, two and three panels per floor respectively.

---

[1]Both these costs are for one panel per floor.

TABLE 11 - TEST RESULTS

	Panel Locations[1]	COST - $ TO FEED FROM PANEL(S) ON Any Floor	Same or Lower	Same Floor Only
1.	211, 213, 213, 214, 215	8,589.95	8,589.95	8,589.95
2.	231, 122, 123, 124, 125, 211, 2121, 213, 214, 215	8,601.65	8,554.98	8,175.70
3.	321, 222, 323, 234, 235, 211, 212, 213, 214, 215, 121, 122, 223, 134, 135	8,308.44	8.112.62	8,126.00
4.	321, 211, 121, 212, 122, 213, 123, 214, 124, 215, 125	8,042.83	8,042.83	7,970.47
5.	21, 12, 32, 23 on all five floors	8,978.47	8,978.47	8,978.47
6.	211, 231, 213, 233	9,588.58	9,792.25	-
7.	231, 212, 323, 234, 225	8,611.46	9,171.29	10,560.75
8.	211, 231, 212, 323, 234, 225	8,513.99	9,118.72	9,618.97
9.	211, 231, 232, 223, 324, 124	8,253.65	8,916.25	-
10.	9 panels on first floor	7,751.89	7,751.89	-
11.	9 panels on second floor	7,839.71	-	-
12.	1 panel in the center of each floor	9,175.65	9,175.65	9,175.65

Notes:
1. Each digit of the numbers indicate x, y and z grid coordinate respectively.
2. Test 1 is best design for one panel per floor, determined from simulation model.
3. Test 2 is best design for two panels per floor, determined from simulation model.
4. Test 3 is best design from three panels per floor, determined from simulation model.
5. Test 4 is best design derived from taking lowest cost design for each floor.
6. Tests 5-11 inclusive are trials only and other designs may exist which result in reduced costs.

(3) No general rule can be formulated as to whether it is always advantageous to feed a load from a panel on:
   (a) the same floor only, or
   (b) the same or a lower floor only, or
   (c) the basis of nearest regardless of floor.

Analysis of Findings

Traditionally, the purpose of a distribution system has been to reduce the amount of branch circuit wire and conduit at the expense of feeder lengths. The results in this study indicate however, that when one panel is placed on each floor it should be positioned in the segment that minimizes the length of the feeder. A further analysis reveals the reason for this unexpected result.

Consider the typical load in each segment of the building under study. A load of 4700 watts requires four, fifteen amp circuits of which three circuits can be fed from a three phase breaker. Thus six conductors in a 3/4 inch conduit are required to feed the load. The following example, which is based upon the unit costs used in this study illustrates the resulting cost per foot to feed the load.

		Material Cost/Ft.	Labor Cost/Ft.	
Wire - #12: (49.3/1000) x 6	=	.2958	(.8/100)x6x5.55 =	.2664
Conduit-3/4":(19.25/100)	=	.1995	(4.75/100)x5.55 =	.2636
		.4883		.5300
		Total cost/foot		$1.0183

Dividing the above figure by the 15.36 amps[2] required to feed the load yields a cost of $.0663 per amp-foot. Table 12 on the following page indicates the cost per amp-foot for each feeder size. Since the feeder costs per amp-foot are lower than the figure calculated above for branch circuit runs it would appear at first glance to be advantageous to minimize branch circuit lengths at the expense of feeder length. Consider however the case of moving a panel from the grid point (2,2) to (2,1). The distances to three of the loads are decreased by the same amount as the distances to three others are reduced. Thus out of the nine loads on the floor there is a net increase for three only. Thus the increase in branch circuit conduit and wire length is approximately 3/9 that of the feeder length decrease. Comparing 1/3 of .0663 or .0221 it is seen that almost all feeder costs are higher. Thus as indicated by the model it is desirable to locate a single panel per floor at "2,1,1" which minimizes the feeder length.

Table 11 illustrates the cost ($9,175.65) for a design consisting of one panel centered on each floor. This design is intuitively desirable since it centers the panel in the area it is to feed. Without relaxing the "feed from a panel on the same floor only" constraint this cost can be reduced to $7,970.47, a saving of $1,205.18.

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[2]Amps per phase of a three phase balanced load at a power factor of .85.

TABLE 12 - FEEDER COSTS PER AMP-FOOT

	MATERIAL				LABOR IN MAN HOURS					TOTAL		COST/AMP-FOOT	
Row	Wire /Ft.	x4	Cond.	Total	Wire /Ft.	x4	Cond.	Total	x5.55	Cost	Amps	Min	Max
1.	.0406	.1624	.1897	0.3021	.0050	.0200	.0250	.0450	0.2498	0.5519	16	.0345	-
2.	.0493	.1972	.1897	0.3369	.0060	.0240	.0250	.0490	0.2720	0.6089	24	.0254	.0381
3.	.0676	.2704	.1925	0.4629	.0080	.0320	.0300	.0620	0.3441	0.8070	32	.0252	.0336
4.	.1180	.4720	.2671	0.7891	.0100	.0400	.0400	.0800	0.440	1.1881	40	.0296	.0370
5.	.1730	.6920	.4092	1.1012	.0130	.0520	.0550	.1070	0.5939	1.6951	56	.0303	.9424
6.	.2390	.9560	.4092	1.3652	.0160	.0640	.0550	.1190	0.6605	2.0257	72	.0281	.0362
7.	.3390	1.3560	.4092	1.7652	.0165	.0660	.0550	.1210	0.6716	2.4368	80	.0304	.0435
8.	.3880	1.5520	.5215	2.0735	.0175	.0700	.0660	.1360	0.7548	2.8283	100	.0283	.0354
9.	.4420	1.7680	.6735	2.4415	.0200	.0800	.0650	.1450	0.8048	3.2463	120	.0271	.0325
10.	.6900	2.7600	.6735	3.4335	.0285	.1140	.0650	.1790	0.9935	4.4270	160	.0214	.0369
11.	.8580	3.4320	.6735	4.1055	.0340	.1360	.0650	.2010	1.1156	5.2211	180	.0290	.0326
12.	1.0370	4.1580	2.0115	6.1695	.0360	.1440	.1600	.3040	1.6872	7.8567	200	.0393	.0436
13.	1.2740	5.0960	2.0115	7.1075	.0370	.1560	.1600	.3160	1.7538	8.8613	240	.0369	.0443
14.	1.6970	6.1880	2.7682	9.5562	.0445	.1780	.1900	.368-	2.0424	11.5986	280	.0414	.0483
15.	2.2780	9.1120	3.7328	12.8448	.0520	.2080	.2200	.4280	2.3754	15.2202	320	.0476	.0544

Notes:

1. Amps = Amps per phase.
2. Min. cost based on maximum amps.
3. Max. cost based on minimum amps before next smaller size feeder used.
4. All costs expressed as dollars.

Evaluation of the Model

Current industry practice for designing an electrical distribution network consists of (1) deciding how many panels to locate on a floor on the basis of intuitive judgement[3] and (2) locating the panels as near to the center of the areas to be served from each as possible.[4] Summaries of loads connected to each panel are developed as the branch circuit conduits runs are drafted on to the floor plans. Economics in almost all cases precludes the analysis of more than one design.

By recording the load requirements in each segment of the building an analysis of a few designs could be carried out with hand calculations. Such an analysis could consist of (1) providing enough panels per floor so that the feeders required are 180 amps or less,[5] and (2) locating the panels in a trial and error fashion using the cost per amp foot of feeders and branch circuit runs as a guide. While this procedure is likely to lead to a refinement over a design based solely on intuitive judgement the time required for calculations would prevent extensive analysis.

---

[3]Based upon experience as to how large an area can be served before (a) conduit runs get too long for voltage drop re-requirements, (b) more circuits are required than can be contained in a single tub and (c) on the basis of natural building divisions such as wings.

[4]Depending upon locations of walls in which the panels can be suitable mounted.

[5]Since larger feeders have higher costs per amp-foot and costs were found to be insensitive to the number of panels provided this procedure is likely to lead to an improvement.

Since the procedure requires recording load requirements it saves only the computer costs. This saving would likely be exceeded by the costs for manually calculating the costs related to a single layout.

An estimate of the costs that would be incurred in performing a study with the simulation model presented in this study are shown in illustration "F" below:

ILLUSTRATION F

COST ESTIMATE OF A STUDY

Laying out grid network	1 hr @ $7/hour	$ 7.00
Recording load requirements	5 hrs @ $7/hour	35.00
Keypunching of cards		5.00
Computer running cost		9.50
Analysis of results	1 hr @ $7/hour	7.00
		$ 63.50

The computer running cost is for running the simulation program which tests 180 different designs on every floor. While the model presented in this study does not provide any answers which cannot be obtained by an analysis supported by hand calculations it does provide a more complete analysis than can be carried out by other means at many times the cost.

If the design consisting of one panel per floor, centered on each floor is assumed to be the design which would be chosen in the absence of a quantitative analysis then a saving of $1,205.18 is obtained for an investment of $63.50. In addition the model alleviates the need for the conventional analysis of how many

panels to provide, where to locate them, number of circuits required for each panel, feeder sizes required and verifies that voltage drop on feeders is within limits.

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APPENDIX

COMPUTER PROGRAM LISTINGS

ILLUSTRATION-G
SIMULATION MODEL
PROGRAM LISTING

```
FORTRAN IV G LEVEL 1, MOD 4            MAIN              DATE = 70364          16/33/10

C      SPECIFICATION SECTION
       INTEGER X,Y,Z,PX,PY,PZ,A,NP,B,C,J,K,MX,MY,MZ,VOLT1,VOLT2,L,Q
       INTEGER PTOT,PSIZ,PANEL,WAT1,C,R
       REAL LABOR,SX,SY,SZ,DF,FSCHED
       REAL OEM,FO,PCOST,BCCOST,BWCOST,PTC,PBC,MPH,VD
       INTEGER C10,C11,C12,C13,C14,WAT2,X1,X2,Y1,Y2,Z1,Z2
       DIMENSION LOAD(60,19),LA(15,22)
       DIMENSION FD(15,11),BCCOST(4,2),BWCOST(7,2),PTC(11,3),PBC(15,3)
       DIMENSION PTOT(20,27),PSIZ(20,9),PANEL(20,3),OEM(20),PCOST(20,7)
       DIMENSION MPH(15),C(14),R(5,2)
       DIMENSION FSCHED(15),VO(20)
       DIMENSION FC(5),FMIN(5)
       DATA OEM/20*1./
       DATA PCOST/140*0./,FMIN/5*9000./
       NP=5
       NPA=10
       LABOR=5.55
       VOLT1=120
       VOLT2=208
C      CONSTANT DIFINITION-TABLES
       NAMELIST/NAM1/FSCHED,FO,BCCOST,BWCOST,PTC,PBC,MPH,SX,SY,SZ,VD
       READ(5,NAM1)
       WRITE(6,40)
   40  FORMAT(' ',20X,'FEEDER DATA')
       WRITE(6,41) ((FO(I,J),J=1,11),I=1,15)
   41  FORMAT(15(' ',A5,F7.0,A5,8(F7.2)/))
       WRITE(6,42)
   42  FORMAT('0','BRANCH CKT COSTS')
       WRITE(6,47) ((BCCOST(I,J),J=1,2),I=1,4)
   47  FORMAT(7(' ',2(F7.2)/))
       WRITE(6,44)
   44  FORMAT('0','BRANCH WIRE COSTS')
       WRITE(6,47) ((BWCOST(I,J),J=1,2),I=1,7)
       WRITE(6,45)
   45  FORMAT('0','PANEL TUB COSTS')
       WRITE(6,43) ((PTC(I,J),J=1,3),I=1,11)
   43  FORMAT(15(' ',3(F7.2)/))
       WRITE(6,46)
   46  FORMAT('0','PANEL BREAKER COSTS')
       WRITE(6,43) ((PBC(I,J),J=1,3),I=1,15)
       READ(5,101)MX,MY,MZ
  101  FORMAT(11X,I2,1X,I2,1X,I2)
       WRITE(6,213) MX,MY,MZ
  213  FORMAT('0','MAIN PANEL LOCATED AT',2X,2(I2,','),I2)
       IL=0
       I=0
 2999  CONTINUE
       I=I+1
       READ(5,102) (LOAD(I,J),J=1,19)
  102  FORMAT(3(I2,1X),1X,I5,2X,14(I1,1X),2X,I6)
       WRITE(6,1020) (LOAD(I,J),J=1,19)
 1020  FORMAT(' ',3(I2,1X),1X,I5,2X,14(I1,1X),2X,I6)
       IF(LOAD(I,1).LT.0) GO TO 3001
       GO TO 2999
 3001  CONTINUE
```

```
              I=0
        3002  CONTINUE
              I=I+1
              READ(5,103) (LA(I,J),J=1,22)
        103   FORMAT(6(I2,1X),1X,I5,2X,14(I1,1X),2X,I5)
              WRITE(6,1030) (LA(I,J),J=1,22)
        1030  FORMAT(' ',6(I2,1X),1X,I5,2X,14(I1,1X),2X,I5)
              IF(LA(I,1).LT.0) GO TO 3003
              GO TO 3002
        3003  CONTINUE
              READ(5,104) (R(I,1),R(I,2),I=1,5)
        104   FORMAT(5(I2,1X,I2,2X))
              DO 896 N3Y=1,3
              DO 895 N3X=1,3
              DO 894 N2Y=1,3
              DO 893 N2X=1,3
              DO 892 N1Y=1,3
              DO 891 N1X=1,3
              IF(NP.EQ.5) GO TO 1040
              IF((N2X.EQ.2).AND.(N2Y.EQ.1).AND.(NP.EQ.10)) GO TO 1039
              IF((N2X.EQ.2).AND.(N2Y.EQ.1).AND.(N3X.EQ.3).AND.(N3Y.EQ.1)) GO TO
             K1038
              IF((N1Y.LE.N2Y).AND.(N1X.LE.N2X)) GO TO 999
              IF((N2Y.LE.N3Y).AND.(N2X.LE.N3X)) GO TO 999
        1038  CONTINUE
              IF((N2Y.EQ.N3Y).AND.(N2X.EQ.N3X)) GO TO 999
              IF((N1Y.EQ.N3Y).AND.(N1X.EQ.N3X)) GO TO 999
        1039  CONTINUE
              IF((N1Y.EQ.N2Y).AND.(N1X.EQ.N2X)) GO TO 999
        1040  CONTINUE
              DO 500 A=1,NP
              PANEL(A,1)=N1X
              PANEL(A,2)=N1Y
              PANEL(A,3)=A
              IF(A.LE.5) GO TO 499
              NZ=A-5
              PANEL(A,1)=N2X
              PANEL(A,2)=N2Y
              PANEL(A,3)=NZ
              IF(A.LE.10) GO TO 498
              NZ=A-10
              PANEL(A,1)=N3X
              PANEL(A,2)=N3Y
              PANEL(A,3)=NZ
        498   CONTINUE
        499   CONTINUE
        500   CONTINUE
       C      MAIN PROGRAM
              IL=0
              MCWAT=0
              MDWAT=0
              MAMPS=0
              ISW=0
              DO 5001 I=1,20
              DO 5002 J=1,27
```

```
            PTOT(I,J)=0
      5002  CONTINUE
      5001  CONTINUE
     C      CONVERT LOAD DATA
      300   CONTINUE
            IL=IL+1
            X=LOAD(IL,1)
            IF(X.LT.0) IL=0
            IF(X.LT.0) GO TO 3091
            Y=LOAD(IL,2)
            Z=LOAD(IL,3)
            WAT1=LOAD(IL,4)
            DO 2998 J=1,14
            K=J+4
            C(J)=LOAD(IL,K)
      2998  CONTINUE
            WAT2=LOAD(IL,19)
            DMIN=9000.
            DO 501 A=1,NP
            PX=PANEL(A,1)
            PY=PANEL(A,2)
            PZ=PANEL(A,3)
            IF(Z.NE.PZ) GO TO 301
            D1=(((SZ*(Z-PZ))**2)**.5)+(((SX*(X-PX))**2)+((SY*(Y-PY))**2))**.5
            IF(D1.GT.DMIN) GO TO 301
            DMIN=D1
            NA=A
      301   CONTINUE
      501   CONTINUE
            DIST=DMIN+12.0
            A=NA
     C      BRANCH CKT WIRE REQUIREMENTS
            W1=WAT1
            IF(VOLT1.LT.130.) GBC=W1/1200.
            IF(VOLT1.GT.346.) GBC=W1/3500.
            NBC=GBC
            DIFF=GBC-NBC
            IF(DIFF.GE.0.1) NBC=NBC+1
            C1A=C(1)
            C(1)=C1A+NBC
            DO 502 K=1,14
            PTOT(A,K)=PTOT(A,K)+C(K)
      502   CONTINUE
            MCWAT=MCWAT+WAT1+WAT2
            PTOT(A,16)=PTOT(A,16)+(WAT1+WAT2)*DEM(A)
            N3PH=NBC/3
            DIF2=NBC-(N3PH*3)
            NSP=0
            IF(DIF2.GT..9) NSP=2
            IF(DIF2.GT.1.5) NSP=3
            IF(VOLT1.GT.300.) GO TO 401
            NW1=4*N3PH+NSP+2*C1A+3*C(2)+4*C(3)+2*C(4)+3*C(5)+4*C(6)+2*C(7)+3*C
           K(8)
      302   CONTINUE
            PTOT(A,17)=PTOT(A,17)+DIST*(NW1+2*C(9))
```

```
            PTOT(A,18)=PTOT(A,18)+(3*C(10)+4*C(11))*DIST
            PTOT(A,19)=PTOT(A,19)+4*C(12)*DIST
            PTOT(A,20)=PTOT(A,20)+4*C(13)*DIST
            PTOT(A,22)=PTOT(A,22)+4*C(14)*DIST
      C     BRANCH CKT CONDUIT REQUIREMENTS
            NCON1=0
            NCON2=0
            NCON3=0
        303 CONTINUE
            IF(VOLT1.GT.300) GO TO 402
            IF(NW1.NE.16) GO TO 304
            NCON2=NCON2+2
            GO TO 307
        304 IF(NW1.LE.9) GO TO 305
            NCON3=NCON3+1
            NW1=NW1-15
            GO TO 304
        305 IF(NW1.LE.5) GO TO 306
            NCON2=NCON2+1
            NW1=NW1-9
            GO TO 305
        306 IF(NW1.LE.0) GO TO 307
            NCON1=NCON1+1
        307 CONTINUE
            DIST=DMIN+7.0
            PTOT(A,24)=PTOT(A,24)+DIST*(NCON1+C(9)+C(10))
            PTOT(A,25)=PTOT(A,25)+DIST*(NCON2+C(11))
            PTOT(A,26)=PTOT(A,26)+DIST*(NCON3+C(12))
            PTOT(A,27)=PTOT(A,27)+DIST*(C(13)+C(14))
            IF(ISW.EQ.0) GO TO 300
        308 CONTINUE
      C     ALTERNATE SOURCE LOADS
       3091 CONTINUE
            ISW=10
            IL=IL+1
            X1=LA(IL,1)
            IF(X1.LT.0) GO TO 310
            X2=LA(IL,2)
            Y1=LA(IL,3)
            Y2=LA(IL,4)
            Z1=LA(IL,5)
            Z2=LA(IL,6)
            WAT1=LA(IL,7)
            DO 3082 J=1,14
            K=J+7
            C(J)=LA(IL,K)
       3082 CONTINUE
            WAT2=LA(IL,22)
            DMIN=9000.
            DO 503 A=1,NP
            DO 504 X=X1,X2
            DO 505 Y=Y1,Y2
            DO 506 Z=Z1,Z2
            PX=PANEL(A,1)
            PY=PANEL(A,2)
```

```
      PZ=PANEL(A,3)
      D1=(((SZ*(Z-PZ))**2)**.5)+((SX*(X-PX))**2+(SY*(Y-PY))**2)**.5
      IF(D1.GE.DMIN) GO TO 309
      DMIN=D1
      NA=A
  309 CONTINUE
506   CONTINUE
505   CONTINUE
504   CONTINUE
503   CONTINUE
      GO TO 501
310   CONTINUE
C     CALCULATION OF PANEL PARAMETERS
      WRITE(6,218)
 218  FORMAT('1',10X,'FEEDER SCHEDULE')
      WRITE(6,221)
 221  FORMAT('0','LOCATION ','   AMPS',6X,'LENGTH',2X,'WIRE SIZE')
      DO 514 A=1,NP
      DO 516 I=1,14
      C(I)=PTOT(A,I)
 516  CONTINUE
      PSIZ(A,1)=C(1)+2*C(2)+3*C(3)+C(4)+2*C(5)+3*C(6)+C(7)+2*C(8)+3*C(9)
     K+2*C(10)+3*C(11)+3*C(12)+3*C(13)+3*C(14)
      PSIZ(A,2)=PSIZ(A,1)*.1
      NTUB=PSIZ(A,1)+PSIZ(A,2)+PSIZ(A,1)*.2
      MTUB=120
      IF(NTUB.LE.84) MTUB=84
      IF(NTUB.LE.72) MTUB=72
      IF(NTUB.LE.60) MTUB=60
      IF(NTUB.LE.48) MTUB=48
      IF(NTUB.LE.42) MTUB=42
      IF(NTUB.LE.36) MTUB=36
      IF(NTUB.LE.30) MTUB=30
      IF(NTUB.LE.24) MTUB=24
      IF(NTUB.LE.18) MTUB=18
      IF(NTUB.LE.12) MTUB=12
      PSIZ(A,3)=MTUB
      PSIZ(A,4)=PSIZ(A,3)-PSIZ(A,2)-PSIZ(A,1)
      PTOT(A,15)=PSIZ(A,4)
      PSIZ(A,8)=PTOT(A,16)/(3*VOLT1*.85)
      NF=1
      NA=PSIZ(A,8)
      IF(NA.GT.FSCHED(15)) GO TO 411
 5069 CONTINUE
      Q=1
      DO 507 I=1,15
      IF(NA.GT.FSCHED(I)) Q=I+1
  507 CONTINUE
      PSIZ(A,5)=Q
C     FEEDER LENGTH CALCULATION
      PX=PANEL(A,1)
      PY=PANEL(A,2)
      PZ=PANEL(A,3)
      IF(MZ.EQ.PZ) GO TO 3111
      IT=R(1,1)+R(2,1)+R(3,1)+R(4,1)+R(5,1)
```

```
0264            IF(IT.GT.0) GO TO 409
0265       3111 CONTINUE
0266            DIST=(((SZ*(MZ-PZ))**2)**.5)+((SX*(MX-PX))**2+(SY*(MY-PY))**2)**.5
0267        311 CONTINUE
0268            PSIZ(A,6)=(DIST+6.0)*4.0*NF
0269            PSIZ(A,7)=DIST*NF
0270            I=PSIZ(A,5)
0271            IF(I.GT.15) I=15
0272        314 CONTINUE
0273            VDROP=(VD(I)*DIST*PSIZ(A,8))/(10000.*NF)
0274            VDMAX=.03*VOLT1
0275            IF(VDROP.LT.VDMAX) GO TO 315
0276            I=I+1
0277            WRITE(6,219) I
0278        219 FORMAT('0','NEXT FEEDER RESIZED FOR VOLTAGE DROP TO SIZE NO',I4)
0279            GO TO 314
0280        315 CONTINUE
0281            IF(I.GT.15) WRITE(6,220)
0282        220 FORMAT('0','LARGEST WIRE SIZE TOO SMALL FOR VOLT DROP REQUIRE')
0283            IF(I.GT.15) I=15
0284            PSIZ(A,9)=I
0285            WRITE(6,217) (PANEL(A,N),N=1,3),PSIZ(A,8),DIST,FD(I,1),FD(I,3)
0286        217 FORMAT(' ',2(I2,','),I2,I7,3X,F10.2,7X,A4,' IN A ',A4,' INCH COND'
           K)
0287        514 CONTINUE
          C     COST CALCULATIONS
0288            CFMP=0.
0289            DO 508 A=1,NP
0290            TOT1=0.0
0291            DO 509 J=1,4
0292            TOT1=TOT1+((BCCOST(J,1)/100.)+(BCCOST(J,2)*LABOR/100.))*PTOT(A,J+2
           K3)
0293        509 CONTINUE
0294            TOT2=0.0
0295            DO 510 J=1,7
0296            TOT2=TOT2+((BWCOST(J,1)/1000.)+(BWCOST(J,2)*LABOR/100.))*PTOT(A,J+
           K16)
0297            CONTINUE
0298        510 CONTINUE
0299            PCOST(A,1)=TOT1
0300            PCOST(A,2)=TOT2
          C     PANEL TUB COSTS
0301            J=(PSIZ(A,3)/6)-1
0302            IF(PSIZ(A,3).EQ.60) J=8
0303            IF(PSIZ(A,3).EQ.72) J=9
0304            IF(PSIZ(A,3).EQ.84) J=10
0305            IF(PSIZ(A,3).EQ.120) J=11
0306            IF(J.GE.12) J=11
0307            K=2
0308            IF(VOLT1.LE.250.) K=1
0309            TOT3=PTC(J,K)+PTC(J,3)*LABOR
0310            TOT4=0.0
0311            DO 511 J=1,15
0312            TOT4=TOT4+(PBC(J,K)+LABOR*PBC(J,3))*PTOT(A,J)
0313        511 CONTINUE
```

```
0314            TOT5=PSIZ(A,2)*PBC(1,K)
0315            Q=PSIZ(A,5)
0316            HRS=.035*FD(Q,2)
0317            TOT6=HRS*LABOR
0318            PCOST(A,3)=TOT3+TOT4+TOT5
0319            M=PSIZ(A,9)
          C     FEEDER COSTS-WIRE,CONDUIT,BREAKER COSTS
0320            PCOST(A,4)=((FD(M,4)/1000.)+(LABOR*FD(M,8)/100.))*PSIZ(A,6)
0321            PCOST(A,5)=FD(M,7)+LABOR*FD(M,11)+((FD(M,6)/100.)+(LABOR*FD(M,10)/
               K100.))*PSIZ(A,7)
0322            PCOST(A,6)=FD(Q,5)+(FD(Q,9)*LABOR)
0323            CFMP=CFMP+LABOR*FD(Q,9)/2.
0324            PCOST(A,7)=PCOST(A,1)+PCOST(A,2)+PCOST(A,3)+PCOST(A,4)+PCOST(A,5)+
               KPCOST(A,6)
0325        508 CONTINUE
          C     MAIN PANEL COSTS
0326            TOTMPH=0.
0327            DO 312 A=1,NP
0328            Q=PSIZ(A,5)
0329            TOTMPH=TOTMPH+.5*MPH(Q)
0330        312 CONTINUE
0331            FACT=1.
0332            IF(TOTMPH.GT.52.75) FACT=2.
0333            IF(TOTMPH.GT.105.5) FACT=3.
          C     ABOVE MAIN PANEL COST DOES NOT INCLUDE MTRL COST FOR TUB
          C     TOTALS AND OUTPUT
0334            WRITE(6,209)
0335        209 FORMAT('0',20X,'TABLE OF PANEL TOTALS')
0336            WRITE(6,224)
0337            WRITE(6,225)
0338            WRITE(6,2251)
0339        224 FORMAT('0','PANEL',4X,' 15 ',' 15 ',' 15 ',' 20 ',' 20 ',' 20 ','
               K30 ',' 30 ',' 30 ',' 40 ',' 40 ',' 50 ',' 70 ','100 ','BLANK','  W
               KATTS ','WIRE TOTALS',18X,'BRANCH CKT CONDUIT')
0340        225 FORMAT(' ',9X,' SP ',' 2P ',' 3P ',' SP ',' 2P ',' 3P ',' SP ',' 2
               KP ',' 3P ',' 2P ',' 3P ',' 3P ',' 3P ',' 3P ',15X,' 12 ',' 10 ','
               K 8 ','  6 ','  4 ','  3 ',' 14 ','1/2 ','3/4 ','  1 ','1-1/4')
0341       2251 FORMAT(' ')
0342            WRITE(6,206) ((PANEL(I,N),N=1,3),(PTOT(I,J),J=1,27),I=1,NP)
0343        206 FORMAT(15(' ',2(I2,','),I2,15(I4),I9,I6,10(I4)/))
0344            WRITE(6,210)
0345        210 FORMAT('0',20X,'TABLE OF PANEL SIZE INFORMATION')
0346            WRITE(6,223)
0347        223 FORMAT('0','PANEL',6X,'CIRCUITS ',' SPARES  ','TUB SIZE ','BLANKS
               K ','REF1 SIZE',' FEEDER  ',' CONDUIT ',' DESIGN  ','REF2 SIZE')
0348            WRITE(6,229)
0349        229 FORMAT(' ',55X,' LENGTH  ',' LENGTH  ',' LOAD    ','ADJ FOR VOLT D
               KROP')
0350            WRITE(6,207) ((PANEL(I,N),N=1,3),(PSIZ(I,J),J=1,9),I=1,NP)
0351        207 FORMAT(15(' ',2(I2,','),I2,2X,9(I7,2X)/))
0352            WRITE(6,200)
0353        200 FORMAT('1',20X,'TABLE OF COSTS')
0354            WRITE(6,222)
0355        222 FORMAT('0',3X,'PANEL',5X,'BRANCH COND',3X,'BRANCH WIRE',4X,'PANEL
               KCOST',3X,'FEEDER WIRE',1X,'FEEDER CONDUIT',' BREAKER&CONN')
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```
0356            WRITE(6,208) ((PANEL(I,N),N=1,3),(PCOST(I,J),J=1,7),I=1,NP)
0357       208  FORMAT(15(' ',2X,2(I2,','),I2,2X,7(F12.2,2X)/))
0358            WRITE(6,201) CFMP,FACT
0359       201  FORMAT(' ','MAIN PANEL TUB MOUNTING COST',F7.2,5X,'NO. OF TUBS REQ
               KD ',F2.0)
0360            TCOST=CFMP
0361            DO 313 A=1,NP
0362            DO 324 J=1,6
0363            TCOST=TCOST+PCOST(A,J)
0364       324  CONTINUE
0365       313  CONTINUE
0366            WRITE(6,202) TCOST
0367       202  FORMAT(' ','TOTAL COST IS  ',F10.2)
0368            WRITE(6,290)
0369       290  FORMAT('0','ADD MATERIAL COST FOR MAIN PANEL TUB(S)')
0370            DO 325 I=1,NP
0371            MDWAT=MDWAT+PTOT(I,16)
0372            MAMPS=MAMPS+PSIZ(I,8)
0373       325  CONTINUE
0374            WRITE(6,226) MCWAT
0375       226  FORMAT('0','TOTAL CONNECTED LOAD: ',I8,' WATTS')
0376            WRITE(6,227) MDWAT
0377       227  FORMAT('0','DESIGN LOAD;',I8,' WATTS')
0378            WRITE(6,228) MAMPS
0379       228  FORMAT('0','DESIGN AMPS;',I8)
0380            DO 851 A=1,5
0381            FC(A)=PCOST(A,7)+PCOST(A+5,7)+PCOST(A+10,7)
0382            IF(FC(A).GT.FMIN(A)) GO TO 850
0383            FMIN(A)=FC(A)
0384            WRITE(6,230) A,FC(A)
0385       230  FORMAT(' ','FLOOR',I5,'  LOW COST OF',F10.2)
0386       850  CONTINUE
0387       851  CONTINUE
0388       999  CONTINUE
0389       891  CONTINUE
0390       892  CONTINUE
0391            IF(NP.EQ.5) GO TO 4000
0392       8925 CONTINUE
0393            NP=NPA
0394       893  CONTINUE
0395       894  CONTINUE
0396            IF(NPA.EQ.10) GO TO 4005
0397       8725 CONTINUE
0398            NPA=15
0399       895  CONTINUE
0400       896  CONTINUE
0401            STOP
          C     JUMP IN JUMP OUT AREA
0402       4000 CONTINUE
0403            DO 4001 A=1,5
0404            FMIN(A)=9000.
0405       4001 CONTINUE
0406            GO TO 8925
0407       4005 CONTINUE
0408            DO 4002 A=1,5
```

```
              FMIN(A)=9000.
        4002  CONTINUE
              GO TO 8725
        401   CONTINUE
              NW7=4*N3PH+NSP+2*C1A+3*C(2)+4*C(3)+2*C(4)+3*C(5)+4*C(6)
              NW1=2*C(7)+3*C(8)
              PTOT(A,23)=NW7*DIST+PTOT(A,23)
              GO TO 302
        402   CONTINUE
        403   IF(NW7.LE.11) GO TO 404
              NCON3=NCON3+1
              NW7=NW7-18
              GO TO 403
        404   IF(NW7.LE.6) GO TO 405
              NCON2=NCON2+1
              NW7=NW7-11
              GO TO 404
        405   IF(NW7.LE.0) GO TO 406
              NCON1=NCON1+1
        406   CONTINUE
              GO TO 307
        409   CONTINUE
              NI=5
              IF(R(5,1).EQ.0) NI=4
              IF(R(4,1).EQ.0) NI=3
              IF(R(3,1).EQ.0) NI=2
              IF(R(2,1).EQ.0) NI=1
              DMAX=90000.
              DO 410 I=1,NI
              RX=R(I,1)
              RY=R(I,2)
              D1=((SX*(PX-RX))**2+(SY*(PY-RY))**2)**.5
              D2=SZ*(((MZ-PZ)**2)**.5)
              D3=((SX*(MX-RX))**2+(SY*(MY-RY))**2)**.5
              DIST=D1+D2+D3
              IF(DIST.LT.DMAX) DMAX=DIST
        410   CONTINUE
              DIST=DMAX
              GO TO 311
        411   CONTINUE
              NA=NA/2
              NF=2
              WRITE(6,241) A
        241   FORMAT(' ','NOTE FEEDER TO PANEL',I4,'  IS DOUBLE RUN')
              WRITE(6,242)
        242   FORMAT(' ','BREAKER COST FOR THIS FEEDER INVALID')
              GO TO 5069
              END
```

ILLUSTRATION - H
MANUAL TRIAL MODEL
PROGRAM LISTING

FORTRAN IV G LEVEL 1, MOD 4   MAIN   DATE = 70364   16/31/38

```
C      SPECIFICATION SECTION
       INTEGER X,Y,Z,PX,PY,PZ,A,NP,B,C,J,K,MX,MY,MZ,VOLT1,VOLT2,L,Q
       INTEGER PTOT,PSIZ,PANEL,WAT1,C,R
       REAL LABOR,SX,SY,SZ,DF,FSCHED
       REAL DEM,FD,PCOST,BCCOST,BWCOST,PTC,PBC,MPH,VD
       INTEGER C10,C11,C12,C13,C14,WAT2,X1,X2,Y1,Y2,Z1,Z2
       DIMENSION LOAD(60,19),LA(15,22)
       DIMENSION FD(15,11),BCCOST(4,2),BWCOST(7,2),PTC(11,3),PBC(15,3)
       DIMENSION PTOT(20,27),PSIZ(20,9),PANEL(30,3),DEM(20),PCOST(20,7)
       DIMENSION MPH(15),C(14),R(5,2)
       DIMENSION FSCHED(15),VD(20)
       DATA DEM/20*1./
       DATA PTOT/540*0/
       DATA PCOST/140*0./
       LABOR=5.55
       VOLT1=120
       VOLT2=208
C      CONSTANT DIFINITION-TABLES
       NAMELIST/NAM1/FSCHED,FD,BCCOST,BWCOST,PTC,PBC,MPH,SX,SY,SZ,VD
       READ(5,NAM1)
       WRITE(6,40)
  40   FORMAT(' ',20X,'FEEDER DATA')
       WRITE(6,41) ((FD(I,J),J=1,11),I=1,15)
  41   FORMAT(15(' ',A5,F7.0,A5,8(F7.2)/))
       WRITE(6,42)
  42   FORMAT('0','BRANCH CKT COSTS')
       WRITE(6,47) ((BCCOST(I,J),J=1,2),I=1,4)
  47   FORMAT(7(' ',2(F7.2)/))
       WRITE(6,44)
  44   FORMAT('0','BRANCH WIRE COSTS')
       WRITE(6,47) ((BWCOST(I,J),J=1,2),I=1,7)
       WRITE(6,45)
  45   FORMAT('0','PANEL TUB COSTS')
       WRITE(6,43) ((PTC(I,J),J=1,3),I=1,11)
  43   FORMAT(15(' ',3(F7.2)/))
       WRITE(6,46)
  46   FORMAT('0','PANEL BREAKER COSTS')
       WRITE(6,43) ((PBC(I,J),J=1,3),I=1,15)
       READ(5,101)MX,MY,MZ
 101   FORMAT(11X,I2,1X,I2,1X,I2)
       WRITE(6,213) MX,MY,MZ
 213   FORMAT('0','MAIN PANEL LOCATED AT',2X,2(I2,','),I2)
       IL=0
       I=0
2999   CONTINUE
       I=I+1
       READ(5,102) (LOAD(I,J),J=1,19)
 102   FORMAT(3(I2,1X),1X,I5,2X,14(I1,1X),2X,I6)
       WRITE(6,1020) (LOAD(I,J),J=1,19)
1020   FORMAT(' ',3(I2,1X),1X,I5,2X,14(I1,1X),2X,I6)
       IF(LOAD(I,1).LT.0) GO TO 3001
       GO TO 2999
3001   CONTINUE
       I=0
3002   CONTINUE
```

```
            I=I+1
            READ(5,103) (LA(I,J),J=1,22)
      103   FORMAT(6(I2,1X),1X,I5,2X,14(I1,1X),2X,I5)
            WRITE(6,1030) (LA(I,J),J=1,22)
     1030   FORMAT(' ',6(I2,1X),1X,I5,2X,14(I1,1X),2X,I5)
            IF(LA(I,1).LT.0) GO TO 3003
            GO TO 3002
     3003   CONTINUE
            READ(5,104) (R(I,1),R(I,2),I=1,5)
      104   FORMAT(5(I2,1X,I2,2X))
      498   CONTINUE
            MCWAT=0
            MDWAT=0
            MAMPS=0
            WRITE(6,211)
      211   FORMAT('1',15X,'PANEL LOCATIONS AND DEMAND FACTOR')
            A=0
      499   CONTINUE
            A=A+1
            READ(5,100) (PANEL(A,N),N=1,3),DEM(A)
      100   FORMAT(3(I2,1X),2X,F4.2)
            IF(DEM(A).LT.0.1) DEM(A)=1.0
            WRITE(6,212) (PANEL(A,N),N=1,3),DEM(A)
      212   FORMAT(' ',15X,2(I2,','),I2,8X,F4.2)
            IF(PANEL(A,1).LE.-4) GO TO 9991
            IF(PANEL(A,1).LE.0) GO TO 500
            NP=A
            GO TO 499
      500   CONTINUE
C           MAIN PROGRAM
C           CONVERT LOAD DATA
            IL=0
            ISW=0
      300   CONTINUE
            IL=IL+1
            X=LOAD(IL,1)
            IF(X.LT.0) IL=0
            IF(X.LT.0) GO TO 3091
            Y=LOAD(IL,2)
            Z=LOAD(IL,3)
            WAT1=LOAD(IL,4)
            DO 2998 J=1,14
            K=J+4
            C(J)=LOAD(IL,K)
     2998   CONTINUE
            WAT2=LOAD(IL,19)
            DMIN=9000.
            DO 501 A=1,NP
            PX=PANEL(A,1)
            PY=PANEL(A,2)
            PZ=PANEL(A,3)
            IF(Z.NE.PZ) GO TO 301
            D1=(((SZ*(Z-PZ))**2)**.5)+(((SX*(X-PX))**2)+((SY*(Y-PY))**2))**.5
            IF(D1.GT.DMIN) GO TO 301
            DMIN=D1
```

```
             NA=A
       301   CONTINUE
       501   CONTINUE
             DIST=DMIN+12.0
             A=NA
     C       BRANCH CKT WIRE REQUIREMENTS
             W1=WAT1
             IF(VOLT1.LT.130.) GBC=W1/1200.
             IF(VOLT1.GT.346.) GBC=W1/3500.
             NBC=GBC
             DIFF=GBC-NBC
             IF(DIFF.GE.0.1) NBC=NBC+1
             C1A=C(1)
             C(1)=C1A+NBC
             DO 502 K=1,14
             PTOT(A,K)=PTOT(A,K)+C(K)
       502   CONTINUE
             MCWAT=MCWAT+WAT1+WAT2
             PTOT(A,16)=PTOT(A,16)+(WAT1+WAT2)*DEM(A)
             N3PH=NBC/3
             DIF2=NBC-(N3PH*3)
             NSP=0
             IF(DIF2.GT..9) NSP=2
             IF(DIF2.GT.1.5) NSP=3
             IF(VOLT1.GT.300.) GO TO 401
             NW1=4*N3PH+NSP+2*C1A+3*C(2)+4*C(3)+2*C(4)+3*C(5)+4*C(6)+2*C(7)+3*C
            K(8)
       302   CONTINUE
             PTOT(A,17)=PTOT(A,17)+DIST*(NW1+2*C(9))
             PTOT(A,18)=PTOT(A,18)+(3*C(10)+4*C(11))*DIST
             PTOT(A,19)=PTOT(A,19)+4*C(12)*DIST
             PTOT(A,20)=PTOT(A,20)+4*C(13)*DIST
             PTOT(A,22)=PTOT(A,22)+4*C(14)*DIST
     C       BRANCH CKT CONDUIT REQUIREMENTS
             NCON1=0
             NCON2=0
             NCON3=0
       303   CONTINUE
             IF(VOLT1.GT.300) GO TO 402
             IF(NW1.NE.16) GO TO 304
             NCON2=NCON2+2
             GO TO 307
       304   IF(NW1.LE.9) GO TO 305
             NCON3=NCON3+1
             NW1=NW1-15
             GO TO 304
       305   IF(NW1.LE.5) GO TO 306
             NCON2=NCON2+1
             NW1=NW1-9
             GO TO 305
       306   IF(NW1.LE.0) GO TO 307
             NCON1=NCON1+1
       307   CONTINUE
             DIST=DMIN+7.0
             PTOT(A,24)=PTOT(A,24)+DIST*(NCON1+C(9)+C(10))
```

```
0159           PTOT(A,25)=PTOT(A,25)+DIST*(NCON2+C(11))
0160           PTOT(A,26)=PTOT(A,26)+DIST*(NCON3+C(12))
0161           PTOT(A,27)=PTOT(A,27)+DIST*(C(13)+C(14))
0162           IF(ISW.EQ.0) GO TO 300
0163       308 CONTINUE
         C     ALTERNATE SOURCE LOADS
0164      3091 CONTINUE
0165           ISW=10
0166           IL=IL+1
0167           X1=LA(IL,1)
0168           IF(X1.LT.0) GO TO 310
0169           X2=LA(IL,2)
0170           Y1=LA(IL,3)
0171           Y2=LA(IL,4)
0172           Z1=LA(IL,5)
0173           Z2=LA(IL,6)
0174           WAT1=LA(IL,7)
0175           DO 3082 J=1,14
0176           K=J+7
0177           C(J)=LA(IL,K)
0178      3082 CONTINUE
0179           WAT2=LA(IL,22)
0180           DMIN=9000.
0181           DO 503 A=1,NP
0182           DO 504 X=X1,X2
0183           DO 505 Y=Y1,Y2
0184           DO 506 Z=Z1,Z2
0185           PX=PANEL(A,1)
0186           PY=PANEL(A,2)
0187           PZ=PANEL(A,3)
0188           IF(Z.NE.PZ) GO TO 309
0189           D1=(((SZ*(Z-PZ))**2)**.5)+((SX*(X-PX))**2+(SY*(Y-PY))**2)**.5
0190           IF(D1.GE.DMIN) GO TO 309
0191           DMIN=D1
0192           NA=A
0193       309 CONTINUE
0194      506  CONTINUE
0195      505  CONTINUE
0196      504  CONTINUE
0197      503  CONTINUE
0198           GO TO 501
0199      310  CONTINUE
         C     CALCULATION OF PANEL PARAMETERS
0200           WRITE(6,218)
0201      218  FORMAT(' ',10X,'FEEDER SCHEDULE')
0202           WRITE(6,221)
0203      221  FORMAT('0','LOCATION ','    AMPS',6X,'LENGTH',2X,'WIRE SIZE')
0204           DO 514 A=1,NP
0205           DO 516 I=1,14
0206           C(I)=PTOT(A,I)
0207      516  CONTINUE
0208           PSIZ(A,1)=C(1)+2*C(2)+3*C(3)+C(4)+2*C(5)+3*C(6)+C(7)+2*C(8)+3*C(9)
              K+2*C(10)+3*C(11)+3*C(12)+3*C(13)+3*C(14)
0209           PSIZ(A,2)=PSIZ(A,1)*.1
0210           NTUB=PSIZ(A,1)+PSIZ(A,2)+PSIZ(A,1)*.2
```

```
           MTUB=120
           IF(NTUB.LE.84) MTUB=84
           IF(NTUB.LE.72) MTUB=72
           IF(NTUB.LE.60) MTUB=60
           IF(NTUB.LE.48) MTUB=48
           IF(NTUB.LE.42) MTUB=42
           IF(NTUB.LE.36) MTUB=36
           IF(NTUB.LE.30) MTUB=30
           IF(NTUB.LE.24) MTUB=24
           IF(NTUB.LE.18) MTUB=18
           IF(NTUB.LE.12) MTUB=12
           PSIZ(A,3)=MTUB
           PSIZ(A,4)=PSIZ(A,3)-PSIZ(A,2)-PSIZ(A,1)
           PTOT(A,15)=PSIZ(A,4)
           PSIZ(A,8)=PTOT(A,16)/(3*VOLT1*.85)
           NF=1
           NA=PSIZ(A,8)
           IF(NA.GT.FSCHED(15)) GO TO 411
      5069 CONTINUE
           Q=1
           DO 507 I=1,15
           IF(NA.GT.FSCHED(I)) Q=I+1
       507 CONTINUE
           PSIZ(A,5)=Q
     C     FEEDER LENGTH CALCULATION
           PX=PANEL(A,1)
           PY=PANEL(A,2)
           PZ=PANEL(A,3)
           IF(MZ.EQ.PZ) GO TO 3111
           IT=R(1,1)+R(2,1)+R(3,1)+R(4,1)+R(5,1)
           IF(IT.GT.0) GO TO 409
      3111 CONTINUE
           DIST=(((SZ*(MZ-PZ))**2)**.5)+((SX*(MX-PX))**2+(SY*(MY-PY))**2)**.5
      311  CONTINUE
           PSIZ(A,6)=(DIST+6.0)*4.0*NF
           PSIZ(A,7)=DIST*NF
           I=PSIZ(A,5)
           IF(I.GT.15) I=15
      314  CONTINUE
           VDROP=(VD(I)*DIST*PSIZ(A,8))/(10000.*NF)
           VDMAX=.03*VOLT1
           IF(VDROP.LT.VDMAX) GO TO 315
           I=I+1
           WRITE(6,219) I
      219  FORMAT('0','NEXT FEEDER RESIZED FOR VOLTAGE DROP TO SIZE NO',I4)
           GO TO 314
      315  CONTINUE
           IF(I.GT.15) WRITE(6,220)
      220  FORMAT('0','LARGEST WIRE SIZE TOO SMALL FOR VOLT DROP REQUIRE')
           IF(I.GT.15) I=15
           PSIZ(A,9)=I
           WRITE(6,217) (PANEL(A,N),N=1,3),PSIZ(A,8),DIST,FD(I,1),FD(I,3)
      217  FORMAT(' ',2(I2,','),I2,I7,3X,F10.2,7X,A4,' IN A ',A4,' INCH COND'
          K)
      514  CONTINUE
```

```
            C      COST CALCULATIONS
0264               CFMP=0.
0265               DO 508 A=1,NP
0266               TOT1=0.0
0267               DO 509 J=1,4
0268               TOT1=TOT1+((BCCOST(J,1)/100.)+(BCCOST(J,2)*LABOR/100.))*PTOT(A,J+2
                  K3)
0269          509  CONTINUE
0270               TOT2=0.0
0271               DO 510 J=1,7
0272               TOT2=TOT2+((BWCOST(J,1)/1000.)+(BWCOST(J,2)*LABOR/100.))*PTOT(A,J+
                  K16)
0273               CONTINUE
0274          510  CONTINUE
0275               PCOST(A,1)=TOT1
0276               PCOST(A,2)=TOT2
            C      PANEL TUB COSTS
0277               J=(PSIZ(A,3)/6)-1
0278               IF(PSIZ(A,3).EQ.60) J=8
0279               IF(PSIZ(A,3).EQ.72) J=9
0280               IF(PSIZ(A,3).EQ.84) J=10
0281               IF(PSIZ(A,3).EQ.120) J=11
0282               IF(J.GE.12) J=11
0283               K=2
0284               IF(VOLT1.LE.250.) K=1
0285               TOT3=PTC(J,K)+PTC(J,3)*LABOR
0286               TOT4=0.0
0287               DO 511 J=1,15
0288               TOT4=TOT4+(PBC(J,K)+LABOR*PBC(J,3))*PTOT(A,J)
0289          511  CONTINUE
0290               TOT5=PSIZ(A,2)*PBC(1,K)
0291               Q=PSIZ(A,5)
0292               HRS=.035*FD(Q,2)
0293               TOT6=HRS*LABOR
0294               PCOST(A,3)=TOT3+TOT4+TOT5
0295               M=PSIZ(A,9)
            C      FEEDER COSTS-WIRE,CONDUIT,BREAKER COSTS
0296               PCOST(A,4)=((FD(M,4)/1000.)+(LABOR*FD(M,8)/100.))*PSIZ(A,6)
0297               PCOST(A,5)=FD(M,7)+LABOR*FD(M,11)+((FD(M,6)/100.)+(LABOR*FD(M,10)/
                  K100.))*PSIZ(A,7)
0298               PCOST(A,6)=FD(Q,5)+(FD(Q,9)*LABOR)
0299               CFMP=CFMP+LABOR*FD(Q,9)/2.
0300               PCOST(A,7)=PCOST(A,1)+PCOST(A,2)+PCOST(A,3)+PCOST(A,4)+PCOST(A,5)+
                  KPCOST(A,6)
0301          508  CONTINUE
            C      MAIN PANEL COSTS
0302               TOTMPH=0.
0303               DO 312 A=1,NP
0304               Q=PSIZ(A,5)
0305               TOTMPH=TOTMPH+.5*MPH(Q)
0306          312  CONTINUE
0307               FACT=1.
0308               IF(TOTMPH.GT.52.75) FACT=2.
0309               IF(TOTMPH.GT.105.5) FACT=3.
            C      ABOVE MAIN PANEL COST DOES NOT INCLUDE MTRL COST FOR TUB
```

```
      C     TOTALS AND OUTPUT
            WRITE(6,209)
       209  FORMAT('0',20X,'TABLE OF PANEL TOTALS')
            WRITE(6,224)
            WRITE(6,225)
            WRITE(6,2251)
       224  FORMAT('0','PANEL',4X,' 15 ',' 15 ',' 15 ',' 20 ',' 20 ',' 20 ','
           K30 ',' 30 ',' 30 ',' 40 ',' 40 ',' 50 ',' 70 ','100 ','BLANK',' W
           KATTS ','WIRE TOTALS',18X,'BRANCH CKT CONDUIT')
       225  FORMAT(' ',9X,' SP ',' 2P ',' 3P ',' SP ',' 2P ',' 3P ',' SP ',' 2
           KP ',' 3P ',' 2P ',' 3P ',' 3P ',' 3P ',' 3P ',15X,' 12 ',' 10 ','
           K 8 ','  6 ','  4 ','  3 ',' 14 ','1/2 ','3/4 ','  1 ','1-1/4')
      2251  FORMAT(' ')
            WRITE(6,206) ((PANEL(I,N),N=1,3),(PTOT(I,J),J=1,27),I=1,NP)
       206  FORMAT(15(' ',2(I2,','),I2,15(I4),I9,I6,10(I4)/))
            WRITE(6,210)
       210  FORMAT('0',20X,'TABLE OF PANEL SIZE INFORMATION')
            WRITE(6,223)
       223  FORMAT('0','PANEL',6X,'CIRCUITS ',' SPARES  ','TUB SIZE ','BLANKS
           K ','REF1 SIZE',' FEEDER  ',' CONDUIT ',' DESIGN  ','REF2 SIZE')
            WRITE(6,229)
       229  FORMAT(' ',55X,' LENGTH  ',' LENGTH  ',' LOAD     ','ADJ FOR VOLT D
           KROP')
            WRITE(6,207) ((PANEL(I,N),N=1,3),(PSIZ(I,J),J=1,9),I=1,NP)
       207  FORMAT(15(' ',2(I2,','),I2,2X,9(I7,2X)/))
            WRITE(6,200)
       200  FORMAT('1',20X,'TABLE OF COSTS')
            WRITE(6,222)
       222  FORMAT('0',3X,'PANEL',5X,'BRANCH COND',3X,'BRANCH WIRE',4X,'PANEL
           KCOST',3X,'FEEDER WIRE',1X,'FEEDER CONDUIT',' BREAKER&CONN')
            WRITE(6,208) ((PANEL(I,N),N=1,3),(PCOST(I,J),J=1,7),I=1,NP)
       208  FORMAT(15(' ',2X,2(I2,','),I2,2X,7(F12.2,2X)/))
            WRITE(6,201) CFMP,FACT
       201  FORMAT(' ','MAIN PANEL TUB MOUNTING COST',F7.2,5X,'NO. OF TUBS REQ
           KD ',F2.0)
            TCOST=CFMP
            DO 313 A=1,NP
            DO 324 J=1,6
            TCOST=TCOST+PCOST(A,J)
       324  CONTINUE
       313  CONTINUE
            WRITE(6,202) TCOST
       202  FORMAT(' ','TOTAL COST IS  ',F10.2)
            WRITE(6,290)
       290  FORMAT('0','ADD MATERIAL COST FOR MAIN PANEL TUB(S)')
            DO 325 I=1,NP
            MDWAT=MDWAT+PTOT(I,16)
            MAMPS=MAMPS+PSIZ(I,8)
       325  CONTINUE
            WRITE(6,226) MCWAT
       226  FORMAT('0','TOTAL CONNECTED LOAD: ',I8,' WATTS')
            WRITE(6,227) MDWAT
       227  FORMAT('0','DESIGN LOAD;',I8,' WATTS')
            WRITE(6,228) MAMPS
       228  FORMAT('0','DESIGN AMPS;',I8)
```

```
      DO 5001 I=1,20
      DO 5002 J=1,27
      PTOT(I,J)=0
 5002 CONTINUE
 5001 CONTINUE
  999 CONTINUE
      GO TO 498
 9991 CONTINUE
      STOP
C     JUMP IN JUMP OUT AREA
  401 CONTINUE
      NW7=4*N3PH+NSP+2*C1A+3*C(2)+4*C(3)+2*C(4)+3*C(5)+4*C(6)
      NW1=2*C( 7)+3*C(8)
      PTOT(A,23)=NW7*DIST+PTOT(A,23)
      GO TO 302
  402 CONTINUE
  403 IF(NW7.LE.11) GO TO 404
      NCON3=NCON3+1
      NW7=NW7-18
      GO TO 403
  404 IF(NW7.LE.6) GO TO 405
      NCON2=NCON2+1
      NW7=NW7-11
      GO TO 404
  405 IF(NW7.LE.0) GO TO 406
      NCON1=NCON1+1
  406 CONTINUE
      GO TO 307
  409 CONTINUE
      NI=5
      IF(R(5,1).EQ.0) NI=4
      IF(R(4,1).EQ.0) N(=3
      IF(R(3,1).EQ.0) NI=2
      IF(R(2,1).EQ.0) NI=1
      DMAX=90000.
      DO 410 I=1,NI
      RX=R(I,1)
      RY=R(I,2)
      D1=((SX*(PX-RX))**2+(SY*(PY-RY))**2)**.5
      D2=SZ*(((MZ-PZ)**2)**.5)
      D3=((SX*(MX-RX))**2+(SY*(MY-RY))**2)**.5
      DIST=D1+D2+D3
      IF(DIST.LT.DMAX) DMAX=DIST
  410 CONTINUE
      DIST=DMAX
      GO TO 311
  411 CONTINUE
      NA=NA/2
      NF=2
      WRITE(6,241) A
  241 FORMAT(' ','NOTE FEEDER TO PANEL',I4,'  IS DOUBLE RUN')
      WRITE(6,242)
  242 FORMAT(' ','BREAKER COST FOR THIS FEEDER INVALID')
      GO TO 5069
      END
```